Faculdade de Desporto da Universidade do Porto

Characterization of upper limbs movements of healthy and poststroke adults

(Caracterização dos movimentos dos membros superiores de adultos saudáveis e pós acidente vascular cerebral)

Thesis submitted in fulfilment of the requirements for the degree of Doctor in Physiotherapy by Faculty of Sport of the University of Porto, under the terms of Decree-Law nº 74/2006 24th March.

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“The important thing is not to stop questioning.

Curiosity has its own reason for existing.”

Albert Einstein

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STATEMENT OF ORIGINALITY

I hereby certify that all the work described in this thesis is the original work of the author. Any published (or unpublished) ideas, techniques, or both from the work of others are fully acknowledged by the standard referencing practices.

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ETHICAL DISCLAIMER

Ethical approval for the studies mentioned in this thesis has been granted by the Ethics Committee of Faculdade de Desporto da Universidade do Porto, (process: CEFADE 08.2016- Appendix I), by the Hospital Ethics Committee (Appendix I) and by the Comissão Nacional de Proteção de Dados (Appendix I).

All subjects who participated in the studies were free from any physical impairment and signed an informed consent form (Appendix II). All participants were fully informed about the nature and objectives of the studies (Appendix II).

LIST OF PUBLICATIONS

Journals

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ABSTRACT

Introduction: Upper limb (UL) motor impairment affects numerous poststroke survivors worldwide and its recovery is slow and complex. Evidence of bilateral impairment after stroke is growing, which creates the need to have a healthy reference for the quality of motor performance instead of ipsilesional UL data. Currently, kinematic analysis is considered one of the best ways to improve the understanding about the mechanisms that drive motor recovery, but a set of methodological flaws is hampering this knowledge. **Aims**: To characterize the ULs movement of healthy and poststroke adults, through kinematic analysis, during the performance of drinking and turning on the light tasks. **Methods**: 63 healthy adults and 5 poststroke patients were eligible to perform drinking and turning on the light tasks with both ULs. Poststroke patients were assessed in early sub-acute phase and in the beginning of chronic phase. Tasks movements were captured by a 3D motion capture system, end-point and joint kinematics were analysed and comparisons between tasks and healthy and poststroke adults were made. **Results**: Drinking task has five phases with different motor skills and kinematic strategies that were mainly influenced by age and sex. Turning on the light has a lower handling requirement, when compared to drinking. The different target formats and the different interaction with them seemed to be responsible for differences in kinematic strategies between both tasks performed by healthy adults. Differences were found between the kinematic strategies used by poststroke adults and those of healthy adults. All poststroke patients presented bilateral kinematic alterations in both tasks. **Conclusion**: A comprehensive analysis of kinematic strategies of drinking and turning on the light were made, in order to obtain a reference of the performance of activities of daily living with different handling requirement for poststroke adults. All studied patients showed bilateral kinematic alterations, which supports the implementation of a bilateral assessment and the need to have a healthy reference for the quality of motor performance. Initial severity of stroke and patients' age appear to have been the most important information to explain the extent of kinematic alterations, but stroke location seemed to have conditioned the specificity of deficits as well as the recovery.

KEY WORDS: STROKE; UPPER EXTREMITIES; MOTOR RECOVERY; MOTOR PERFORMANCE QUALITY ASSESSMENT; KINEMATIC ANALYSIS.

RESUMO

Introdução: O comprometimento motor do membro superior afeta muitos sobreviventes pós-AVC em todo o mundo e a sua recuperação é lenta e complexa. A evidência de comprometimento bilateral após AVC está a crescer, levando à necessidade de desenvolver uma referência saudável para a qualidade do desempenho motor, em vez dos dados do membro superior ipsilesional. **Objetivos**: Caracterizar o movimento dos membros superiores de adultos saudáveis e pós-AVC, através da análise cinemática, durante o desempenho das tarefas "beber" e "acender a luz". **Métodos**: 63 adultos saudáveis e 5 pacientes pós-AVC foram elegíveis para desempenhar as tarefas "beber" e "acender a luz" com os dois membros superiores. Os pacientes pós-AVC foram avaliados no início da fase sub-aguda e no início da fase crónica. Os movimentos das tarefas foram captados por um sistema de captura de movimento 3D, variáveis cinemáticas da mão e articulares foram analisadas e foram feitas comparações entre tarefas e entre adultos saudáveis e pós-AVC. **Resultados**: A tarefa beber teve cinco fases com diferentes habilidades motoras e estratégias cinemáticas que foram influenciadas principalmente pela idade e pelo sexo. Acender a luz tem menor exigência manual, quando comparada com o beber. Os formatos diferentes dos alvos e a interação diferente parecem ser responsáveis por diferenças nas estratégias cinemáticas entre as duas tarefas executadas pelos adultos saudáveis. Foram encontradas diferenças entre as estratégias cinemáticas usadas pelos adultos pós-AVC e as usadas pelos adultos saudáveis. Todos os pacientes pós-AVC apresentaram alterações cinemáticas bilaterais em ambas as tarefas. **Conclusão**: Foi feita uma análise abrangente das estratégias cinemáticas das tarefas beber e acender a luz, de modo a obter uma referência do desempenho de atividades da vida diária com diferentes exigências de manualidade para adultos pós-AVC. Todos os pacientes estudados apresentaram alterações cinemáticas bilaterais, o que suporta a implementação de uma avaliação bilateral e a necessidade de ter uma referência saudável para a qualidade do desempenho motor. A severidade inicial do AVC e a idade dos pacientes parecem ter sido as informações mais importantes para explicar a extensão das alterações cinemáticas, mas a localização do AVC parece ter condicionado a especificidade dos défices, bem como a recuperação.

PALAVRAS-CHAVE: ACIDENTE VASCULAR CEREBRAL; MEMBROS SUPERIORES; RECUPERAÇÃO MOTORA; AVALIAÇÃO DA QUALIDADE DA PERFORMANCE MOTORA; ANÁLISE CINEMÁTICA.

LIST OF ABREVIATURES

%	Percent
<	Smaller than
>	Greater than
°	Degrees
3D	Three dimensional
ADL	Activities of daily living
ARAT	Action Research Arm Test
BMI	Body Mass Index
C7	Processus spinous of the 7th cervical vertebra
cm	Centimetres
CNS	Central Nervous System
cUL	Contralesional Upper Limb
DRINK	Drinking
FMA-UE	Fugl-Meyer Assessment Scale for Upper Extremity
ICF	International Classification of Functioning
IJ	Incisura jugularis
iUL	Ipsilesional Upper Limb
kg	kilogram
LAC	Middle part of left acromion
LASIS	Left anterior superior iliac spine
LIGHT	Turning on the light
LINDEX	Distal phalange of left índex
LLELB	Lateral epicondyle of left humerus
LLH	Lateral side of the head of the second left metacarpal
LMELB	Medial epicondyle of left humerus
LMH	Medial side of the head of the fifth left metacarpal
LPSIS	Left posterior superior iliac spine
LRAD	Styloid process of left radius
LTHUMB	Distal phalange of left thumb
LULN	Styloid process of left ulna

m	Meters
MANOVA	Multifactorial Analysis of Variance
MAS	Modified Ashworth Scale
mm	Millimeters
NIHSS	National Institute of Health Stroke Scale
NMU	Number of Movement Units
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
PROCESS	
PX	Processus xiphoideus
RAC	Middle part of right acromion
RASIS	Right anterior superior iliac spine
RINDEX	Distal phalange of right índex
RLELB	Lateral epicondyle of right humerus
RLH	Lateral side of the head of the second right metacarpal
RMELB	Medial epicondyle of right humerus
RMH	Medial side of the head of the fifth right metacarpal
ROM	Range of Motion
RPSIS	Right posterior superior iliac spine
RRAD	Styloid process of right radius
RTHUMB	Distal phalange of right thumb
RULN	Styloid process of right ulna
s	Seconds
SD	Standard deviation
SRRR	Stroke Recovery and Rehabilitation Roundtable
T1	Early sub-acute phase after stroke
T2	Beginning of chronic phase after stroke
UL	Upper Limb
WHO	World Health Organization
WMFT	Wolf Motor Function Test

1. INTRODUCTION

1.1 The global burden of stroke

Stroke is classically characterized as a neurological deficit attributed to an acute focal injury of the central nervous system (CNS) by a vascular cause, including cerebral infarction, intracerebral hemorrhage, and subarachnoid hemorrhage, and is a major cause of disability and death worldwide (Sacco et al., 2013). It is estimated that stroke affects 17 million people in the world each year (S.A.F.E., 2017), of which 1.1 million occurs in Europe (Bejot, Bailly, Durier, & Giroud, 2016). At the turn of the 21st century, stroke incidence in Portugal was among the highest in Western European countries: 305/100,000 in rural and 269/100,000 in urban populations (Correia et al., 2004). However, over the last two decades, in Portugal and across Europe, there has been a reduction in the proportion of people having a stroke, due to advances in care quality during acute phase and in primary prevention (Bejot et al., 2016; Correia et al., 2017). Although global stroke incidence is declining, rates observed in young adults are on the rise and because of the ageing population, the absolute number of stroke is expected to dramatically increase in coming years (Bejot et al., 2016).

Most patients with stroke survive the initial illness, and a large proportion of them remain with significant impairments (Peter Langhorne, Bernhardt, & Kwakkel, 2011; Peter Langhorne, Coupar, & Pollock, 2009). The most common and widely recognized impairment caused by stroke is motor impairment, which can be regarded as a loss or limitation of function in muscle control or movement or a limitation in mobility (Peter Langhorne et al., 2009). Motor impairment after stroke typically disturbs the control of movement of the face, upper limb (UL) and leg, and affects about 80% of patients (Peter Langhorne et al., 2009). Consequently, one of the greatest health effects for patients, their families and the economy results from the long-term physical consequences of stroke (Brewer, Horgan, Hickey, & Williams, 2013; Peter Langhorne et al., 2011). Therefore, the recovery and the return to a full life following stroke become the main goals for stroke survivors, caregivers and health professionals (Peter Langhorne et al., 2009; Walker et al., 2017). The focus of stroke rehabilitation, and in particular the work of physiotherapists, is on the recovery of impaired movement and the associated functions (Peter Langhorne et al., 2009).

UL motor recovery seems to be particularly slower and more complex than that of the lower limb, which could result from the greater emphasis placed on retraining gait and mobility in an effort to mobilize the patient as quickly as possible and to minimize costly hospital stays (Duncan et al., 1994). Another plausible explanation is that, unlike lower limbs, ULs perform a wide range of activities of daily living (ADL) involving varied interactions with diverse objects and a complex multi-joint coordination (Levin, Kleim, & Wolf, 2009).

1.2 Motor impairment of both upper limbs after stroke

Motor impairment can be caused by ischaemic or haemorrhagic injury to the motor cortex, premotor cortex, motor tracts, or associated pathways in the cerebrum or cerebellum (Warlow et al., 2008). Motor impairment of contralesional UL (cUL) is particularly worrying as more than 80% of stroke survivors experience acute sensorimotor dysfunction of this limb (Cramer et al., 1997), which becomes chronic for 50% of the patients (Kwakkel, Kollen, van der Grond, & Prevo, 2003). UL dysfunction is responsible for limitation of activities (disability) and reduced participation (handicap) of survivors in everyday life situations (Peter Langhorne et al., 2009), such as feeding, dressing, grooming and handwriting, which affects severely their quality of life (Godwin, Ostwald, Cron, & Wasserman, 2013).

Contralesional impairment increase reliance on the ipsilesional UL (iUL) for function and independence (Wetter, Poole, & Haaland, 2005). However, increasing number of studies (Bustren, Sunnerhagen, & Alt Murphy, 2017; Desrosiers, Bourbonnais, Bravo, Roy, & Guay, 1996; Metrot et al., 2013; Noskin et al., 2008; Nowak et al., 2007; Sunderland, Bowers, Sluman, Wilcock, & Ardron, 1999; Wetter et al., 2005) have reported deficits in iUL after a unilateral stroke.

Several bilateral neural mechanisms may be behind the dysfunction of iUL. A dominant theory suggests that the ipsilesional uncrossed descending corticospinal pathways may play a role in the movement of iUL. In fact, approximately 10% to 15% of the corticospinal pathways from cortex to distal muscles run uncrossed through the spinal cord and therefore can also affect the function of iUL (Shumway-Cook & Woollacott, 2017). Alternatively, a body of evidence supports the importance of interhemispheric transcallosal interactions (Grefkes & Fink, 2011; Shimizu et al., 2002; Ward & Cohen, 2004). In planning and execution of targeted unilateral actions, activity in both hemispheres has been reported (Favre et al., 2014). This suggests that damage in one hemisphere also disturbs the neural processing between the hemispheres. Beyond this, both reticular and vestibular systems innervate body musculature ipsi- and contralaterally (Bassoe Gjelsvik & Syre, 2016). Therefore, a stroke affecting motor pathways on one side of the brain may result in reduced motor control on both sides (Silva et al., 2014).

This is not a new concept in stroke research and rehabilitation, but it continues to be poorly recognized (Kitsos, Hubbard, Kitsos, & Parsons, 2013). Health professionals commonly use iUL (often referred to as “nonaffected”) as a measure of reference and control for recover and research, respectively (Kitsos et al., 2013). However, if iUL is used as reference and control for cUL, cUL impairment may be underestimated (Bustren et al., 2017), and therefore, it is necessary to consider bilateral impairment in UL assessment and to use a healthy reference instead of iUL data.

1.3 Motor recovery after stroke

Recovery after stroke is a heterogeneous and complex process that probably occurs through a combination of spontaneous and learning-dependent processes (Kwakkel, Kollen, & Lindeman, 2004). Spontaneous recovery refers to improvements in recovery of behavior in the absence of a specific, targeted treatment and occurs during a time-sensitive window that begins early after stroke and slowly tapers off (Bernhardt et al., 2017). For UL movement, this window may last from weeks to months after stroke (Nakayama, Jorgensen, Raaschou, & Olsen, 1994). Motor (re)learning would depend on the reacquisition of elemental motor patterns (such as muscle or movement synergies, and learning how to apply them in different combinations to accomplish desired motor tasks) or, in the absence of reacquisition, adaptation of remaining or integration of alternative motor elements (Levin et al., 2009). Currently, it is assumed that, after stroke, changes in motor ability might occur via restitution (which reflects the process toward ‘‘true recovery’’) or compensation (Bernhardt et al., 2017). In accordance with the World Health Organization (WHO) International Classification of Functioning (ICF) framework, Levin *et al.* (2009), proposed definitions of motor recovery and motor compensation at three different levels: health condition (neuronal), body functions/structure (performance) and activity (functional). In these three areas, motor recovery relates to: restoration of function in neural tissue that was initially lost; restoration of ability to perform movement in the same way as before injury; and successful task completion as typically done by individuals who are not disabled, respectively. Types of motor compensation in these three areas include: the acquisition by neural tissue of a function that it did not have before the injury; performance of a movement in a new way; and successful task completion by use of different techniques, respectively (Levin et al., 2009).

The greater the severity of sensorimotor impairment, the greater the tendency for the development of compensatory movement patterns to improve functional ability (Levin et al., 2009). The use of increased trunk movement to aid in hand positioning/orientation for grasping is an example of adaptive compensatory strategies (Michaelsen, Jacobs, Roby-Brami, & Levin, 2004). However, although compensatory movements may help patients perform tasks in the short term, the presence of compensation may be associated with long-term problems such as reduced range of joint motion and pain (Levin, 1996b). Therefore, the focus of stroke rehabilitation is to improve functional ability by recovery of premorbid movement patterns.

1.4 Motor performance quality measurement

Motor performance quality measures should be selected to distinguish recovery of premorbid movement patterns from alternative movement patterns adopted by or taught to the patient to compensate the loss of these movement patterns (Levin et al., 2009). Many studies use clinical measures to evaluate impairment and functional change after stroke. Impairment scales, such as Fugl-Meyer Assessment Scale (FMA) (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975), measure specific motor aspects that may limit but are not related to task accomplishment (e.g. strength and isolated joint motion), whereas functional scales, such as the Action Research Arm Test (ARAT) (Yozbatiran, Der-Yeghiaian, & Cramer, 2008), measure the level of task success (Levin et al., 2009). Scores on functional scales may improve either when the intervention results in improvements in motor patterns or in increasing compensations and the distinction between them is not clear (Levin et al., 2009). Although impairment scales may offer the clinician an appreciation of specific motor deficits (Levin et al., 2009), they are strongly influenced by the observer's experience (Patterson, Bishop, McGuirk, Sethi, & Richards, 2011), which makes them subjective. In contrast, the kinematic analysis allows an accurate and objective assessment of the ULs motor functions by providing objective and quantitative parameters (Murphy, Willen, & Sunnerhagen, 2011; Ozturk, Tartar, Huseyinsinoglu, & Ertas, 2016; Patterson et al., 2011; van Dokkum et al., 2014). Therefore, currently, it is considered as one of the best ways for differentiate restitution from compensation and to improve the understanding about the mechanisms that drive motor recovery (Kwakkel et al., 2017).

1.4.1 Kinematic analysis

Kinematic measures of the movement endpoint (hand), whole trajectories and joint angles can be used to address questions about movement quality after stroke (Kwakkel et al., 2017). Based on the theories of UL movement planning, these metrics can be classified into two categories: end-point kinematic metrics and joint kinematic metrics (de los Reyes-Guzmán et al., 2014; Shumway-Cook & Woollacott, 2017). End-point kinematic metrics are widely calculated by three-dimensional (3D) Cartesian coordinates of hand and include several linear metrics, which can characterize for example speed, efficiency, smoothness and control strategy of movement. Joint kinematic metrics include joint range of motion, which can characterize functional range of motion (de los Reyes-Guzmán et al., 2014). Trunk displacement has also been used to quantify compensatory strategies and may also be considered within joint kinematics (Ozturk et al., 2016). Therefore, it is possible to determine whether a given movement is compensatory or becoming more similar to a normal movement (Kwakkel et al., 2017).

Kinematic data can be obtained during performance of motor tasks, generally categorized into functional movements (e.g. reaching movements and path drawing) and ADLs (de los Reyes-Guzmán et al., 2014; Ozturk et al., 2016; van Tuijl, Janssen-Potten, & Seelen, 2002). Several authors (de los Reyes-Guzmán et al., 2014; Kim et al., 2014; Murphy et al., 2011) state that the analysis of goal-oriented tasks, such as performing an ADL, increases the validity of studies. It has been reported that movements are smoother, faster, more forceful, and preplanned for the goal-directed tasks in a natural setting than for the tasks in a simulated context (Trombly & Wu, 1999; O. Wu et al., 2015). Therefore, as task constraint and goal affects the movement, if kinematic assessment include purposeful tasks performed within a natural context, it may reflect the specific difficulties of a poststroke adult's daily life (Shumway-Cook & Woollacott, 2017; C. Wu, Trombly, Lin, & Tickle-Degnen, 1998).

Some authors (Kim et al., 2014; Murphy et al., 2011; Thies et al., 2009) have been selecting the drinking task to kinematically analyse the ULs of poststroke adults. In fact, this seems to be a rich task for kinematic analysis as it includes subtasks such as reaching, grasping, transporting, and manipulating an object, which allows the study of these different motor skills. However, some of these authors (Murphy, Murphy, Persson, Bergstrom, & Sunnerhagen, 2018; Murphy et al., 2011), focused their analysis on the reaching phase without analyzing the pre-shaping that precedes the glass grasping or the other referred motor skills needed in so many other ADLs. On the other hand, the accomplishment of drinking task may become difficult or even impossible in poststroke adults with hand impairment. During pre-shaping for grasping a target, while poststroke adults with mild to moderate impairment may show an extensive opening of the fingers (Nowak et al., 2007), those with more severe impairment usually have problems to open the fingers accurately (Lang et al., 2005), which makes it difficult not only the grasp of the object, but also its release. Consequently, it is necessary to select other less challenging ADLs that these subjects can accomplish. Moreover, considering the great variety of objects with which the human being interacts every day, it is important to know the kinematic strategies used by poststroke adults in other ADLs, to make quality assessment of motor performance more robust and valid (Murphy, 2013).

In the last decade, 3D kinematics of ULs of healthy and poststroke adults were studied in order to better understand UL motor complexity, as well as its motor recovery after stroke, respectively (de los Reyes-Guzmán et al., 2014). The knowledge of typical movement (performed by healthy adults) is the foundation for the identification of kinematic alterations presented by poststroke adults. However, in some of these studies, healthy participants were much younger than those belonging to the poststroke groups (Aizawa et al., 2010; Kim et al., 2014); the possible influence of their sex (Aprile et al., 2014; Kim et al., 2014; Murphy, Sunnerhagen, Johnels, & Willen, 2006; Murphy et al., 2011) and handedness (Aprile et al., 2014; Kim et al., 2014; Murphy et al., 2006) were omitted; the anthropometric characteristics were unknown (Maitra & Junkins, 2004; Murphy et al., 2011; Thies et al., 2009) and the experimental setup was not normalized to these characteristics (Aprile et al., 2014; Murphy et al., 2006; Murphy, Willen, & Sunnerhagen, 2013; Murphy, Willén, & Sunnerhagen, 2012; Murphy et al., 2011). In addition to the aforementioned task constraints affecting movement, age, sex, body mass index (BMI), and handedness may also be responsible for variations in kinematic outcomes. Evidence shows that age (Fradet, Lee, & Dounskaia, 2008; Morgan et al., 1994; Pohl, Winstein, & Fisher, 1996; Vrtunski & Patterson, 1985; Welford, 1982; Williams, 1990), sex (Nakatake, Totoribe, Chosa, Yamako, & Miyazaki, 2017), BMI (AlAbdulwahab & Kachanathu, 2016) and handedness (Solodkin, Hlustik, Noll, & Small, 2001) are responsible for differences in postural control, mobility skills and in the functional organization of motor areas. Therefore, the findings of studies conducted so far in healthy adults do not ensure that there is a valid motor performance reference for poststroke adults.

With respect to stroke recovery studies, a lack of a standardized approach has been identified in their methodology, which is hampering the ability to advance understanding of recovery mechanisms, devise better treatments and consolidate knowledge from a body of research using meta-analyses (Bernhardt et al., 2016; Kwakkel et al., 2017; Peter Langhorne et al., 2009). Despite stroke describes a very heterogeneous group of clinical conditions that are unified by a vascular injury, but not by size, location, or impact, stroke research is often designed with a "one size fits all" point of view (Boyd et al., 2017). Furthermore, patient descriptions are not standardized, age groups and gender differences are not often considered, measures are taken at arbitrary time points relative to stroke onset and a core set of kinematic outcomes is not established (Bernhardt et al., 2016). These recognized problems led to the first Stroke Recovery and Rehabilitation Roundtable (SRRR), held in May 2016, with the aim of achieving an agreed approach to the development, conduct and reporting of research (Bernhardt et al., 2016). Consensus was achieved on priority areas, including the standardized measurement of sensorimotor recovery, resulting in the publication of a core set of recommendations for demographic and stroke information collection (Kwakkel et al., 2017). Better knowledge of patients' profiles not only will help to design better trials in terms of adequate stratification, but also will generate new and better hypotheses about how therapies, including physiotherapy, work and the underlying mechanisms of recovery (Kwakkel et al., 2017).

1.4.2 Importance of kinematic analysis for Physiotherapy in stroke rehabilitation

Stroke rehabilitation involves multidisciplinary teams, in which physiotherapy is a key component (P. Langhorne & Pollock, 2002). As mentioned earlier, the focus of physiotherapy on stroke rehabilitation is the recovery of impaired movement and associated functions. However, the absence of a valid measurement of the quality of motor performance of both ULs is hampering not only the knowledge of typical movement, i.e. which is intended to be recover through physiotherapy, but also knowledge of atypical movement of both ULs caused by stroke. The limitation of this knowledge may hinder the development and validation of effective intervention strategies and procedures in UL motor recovery after stroke. Therefore, kinematic analysis of both ULs of healthy and poststroke adults through an evidence-based approach and respecting the most recent recommendations becomes important to develop up-to-date scientific knowledge regarding typical UL movement patterns and those resulting from a stroke, as well as more effective physiotherapy intervention models. Can physiotherapists play an active role in the development of this knowledge?

Physiotherapy is moving beyond the technical application that once dominated the profession (Rutherford & Kozey, 2014). In stroke rehabilitation context, physiotherapists often contribute with in-depth knowledge of movement analysis, which is necessary in order to observe and analyse how poststroke adults use their bodies to reach functional goals in everyday life (Frykberg & Vasa, 2015), as well as to support the clinical reasoning underlying the therapeutic strategies and procedures that are employed in physiotherapy. The need to base the practice of physiotherapy on scientific evidence and make movement analysis more objective, has led to the integration of 3D motion capture systems in research and clinical practice in physiotherapy. Therefore, investigating pathological and non-pathological movement qualities is a recognized role of physiotherapists (Rutherford & Kozey, 2014).

1.5 Thesis objectives

Main objective of this thesis was defined in consideration of: (i) the slow and complex motor recovery of UL affecting numerous poststroke survivors worldwide; ii) the growing but poorly recognized evidence of bilateral impairment after stroke; iii) the need to have a valid healthy reference for the quality of motor performance while performing ADLs; and iv) the requirement to kinematically analyse poststroke adults motor performance according to the most current recommendations.

Thus, the main objective of this thesis was to characterize the ULs movements of healthy and poststroke adults, through kinematic analysis, during the performance of drinking and turning on the light tasks. The specific objectives defined were:

i. To analyse the kinematic strategies used by healthy adults during drinking task;
ii. To compare the kinematic strategies used by healthy adults in two tasks with different handling requirement: drinking and turning on the light tasks;
iii. To investigate the kinematic strategies used by poststroke adults during the selected ADLs and compare them with those of healthy adults.

2. THESIS ORGANISATION

This PhD thesis is organized in six main topics that are structured in sections. Initially, the work developed is described in a topic that translates the rationale between each article (section 3). Subsequently, several methodological considerations that were not detailed in the articles are presented and justified (section 4). The following topic presents five scientific articles already published or submitted to relevant journals in the field, selected for their contribution to the research objectives of this thesis (section 5). This topic is followed by a discussion of the overall research outcomes (section 6). Finally, the main conclusions and future work perspectives are described (section 7), and the relevant contributions to other scientific projects are presented (section 8).

3. DESCRIPTION OF THE WORK DEVELOPED

The complex motor recovery of ULs after stroke was the trigger for the elaboration of this thesis. The need to optimize the assessment of motor performance quality after stroke, through kinematic analysis, defined the next steps, namely the elaboration of five scientific articles. Thesis organization is summarized in the figure 1.

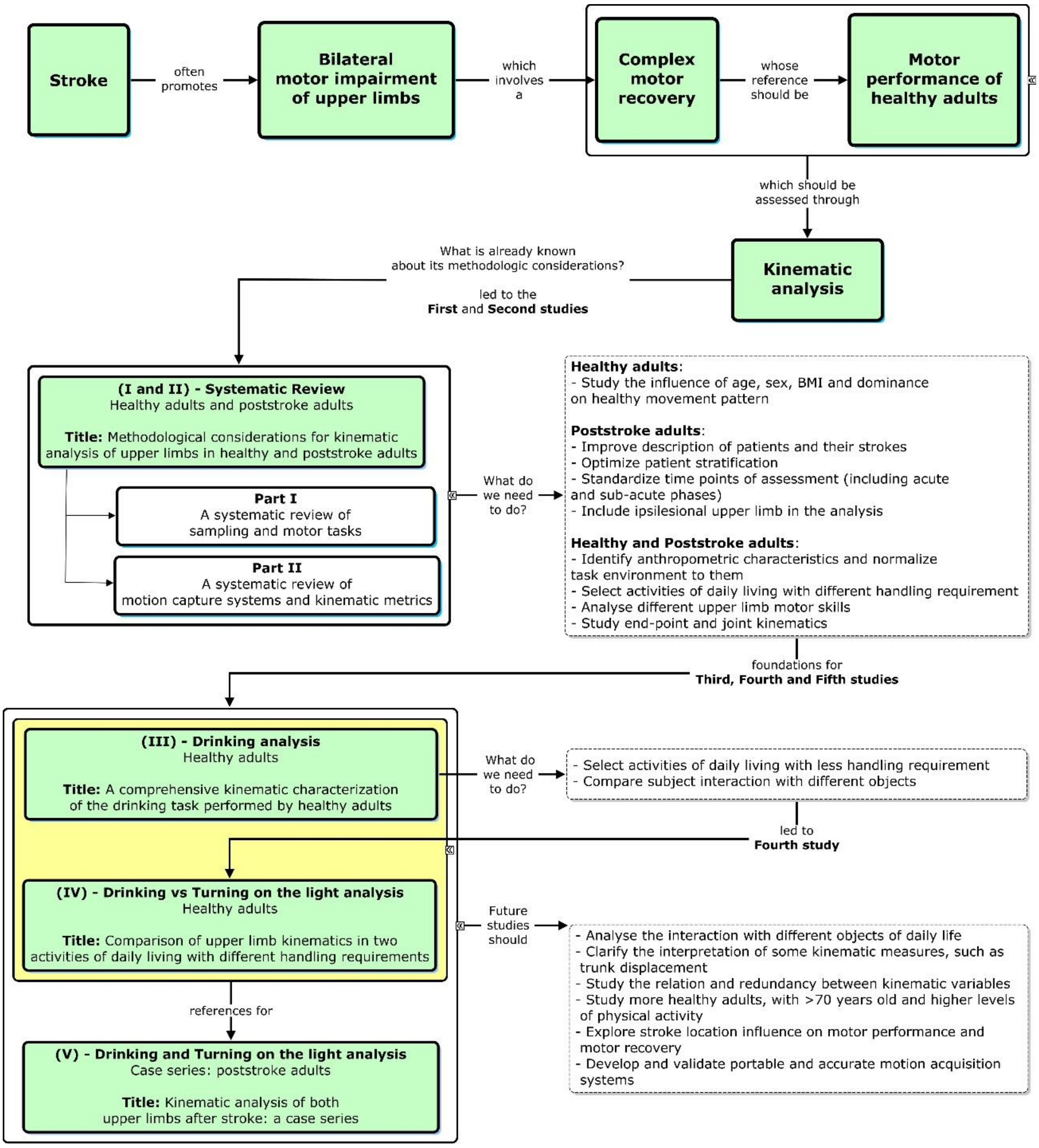


Figure 1. Thesis organization diagram

Our first two studies were two parts of a systematic review of literature, regarding methodological considerations for kinematic analysis of upper limbs in healthy and poststroke adults. The specificities of sampling and motor tasks, as well as the motion capture systems and kinematic metrics used in this specific kinematic analysis were reviewed in the first and second parts, respectively. These two studies were important to define the methodological strategies of the following studies. In our systematic review we analysed articles that studied objectively three-dimension kinematics of ULs of healthy and/or poststroke adults, during the performance of functional movements or ADLs involving the ULs. Usually, healthy participants are young adults and the influence of sex, BMI and dominance on their movement pattern are not analysed; few articles identified anthropometric characteristics and normalized the experimental setup to them; most articles with healthy participants studied simulations of ADL; and most authors analysed joint kinematics or end-point kinematics, mainly related with reaching. From this point on, it became clear the need to: i) study the influence of age, sex, BMI and dominance; ii) identify anthropometric characteristics and normalize the experimental setup to them; iii) select ADLs with greater and lesser difficulty; iv) analyse different UL motor skills; and v) study end-point and joint kinematics. For these reasons, we chose to develop the two following studies.

The third study aimed to describe the kinematic ULs strategies of healthy adults during an ADL, namely drinking task, and to understand if age, sex, dominance and BMI exerted any effect on the strategies used. We chose drinking task because it is an ADL that allows the study of various motor skills, such as reaching, concentric and eccentric transporting and hand aperture to grasp and to release. This study was innovative because it included: i) a sample of healthy adults with a wide age range, with both sexes and two categories of BMI (normal and overweight); ii) a comprehensive analysis of drinking task, and its different motor skills, performed by dominant and non-dominant ULs; iii) a wide set of end-point and joint kinematics; iv) the normalization of the base of support and the glass location to the anthropometric characteristics of each participant; and v) the study of the influence of age, sex, BMI and dominance on motor stratetagies.

Our fourth study emerged from the need to study other ADLs with less demanding handling, which poststroke adults with hand impairment could perform. In this study we chose to select the turning on the light ADL, whose interaction with the switch (pressing it) seems to be easier. Although the interaction with the target is clearly different, drinking and turning on the light tasks share two common gestures, which makes them comparable: i) reaching an object and ii) returning to the starting position. Therefore, besides describing the kinematic strategies of ULs to perform turning on the light task, we considered relevant to understand the implications of two different interactions with two different objects on the kinematic variables analysed. Thereby, the main objective of this study was to compare the kinematic strategies used by the ULs of the healthy adults in an ADL with less demanding handling (turning on the light) with those used in a more difficult ADL (drinking). In addition, we studied if turning on the light kinematic strategies were significantly different between dominant and non-dominant UL, as well as between subjects with different age, sex and BMI. To our knowledge, no other study about kinematic analysis of the ULs analysed turning on the light task or an ADL with less demanding handling and compare them with drinking or other ADL with greater difficulty. This and the third study have provided a kinematic reference of the healthy motor performance of two ADLs to poststroke adults (with greater or lesser hand impairment).

In our systematic review we confirmed also that in studies with poststroke adults: i) most of the recommended demographic and stroke information, were not collected; ii) moment of poststroke assessment was chronic phase whose time interval varied greatly; and iii) iUL was not included in the analysis. Therefore, the aim of the fifth study was to analyse the kinematic strategies of both ULs of poststroke adults in the early sub-acute phase and in the beginning of chronic phase, through a case series and with a methodological approach that included: i) the characterization of patients and their stroke, recommended by SRRR (Kwakkel et al., 2017); ii) the selection of drinking and turning on the light tasks; iii) the normalization of tasks environment to the anthropometric characteristics of each patient; and, iv) the bilateral analysis of "end-point kinematics" and "joint kinematics". This approach intended to contribute to: i) the optimization of poststroke patients’ stratification; ii) the inclusion of patients with hand impairment; iii) the improvement of the experimental setup underlying the UL kinematic analysis; and iv) the implementation of bilateral kinematic assessment.

However, as some questions still need to be answered, in future studies, it will be important to replicate our experimental methodologies and analyse the interaction with different objects of daily life; clarify the interpretation of some kinematic measures, such as trunk displacement; study the relation and redundancy between kinematic variables; study more healthy adults, with >70 years old and higher levels of physical activity; explore stroke location influence on motor performance and motor recovery; and develop and validate portable and accurate motion acquisition systems. The guidelines for future studies will be addressed in more detail in section 7 (conclusions and future work perspectives).

This section showed the work developed during this PhD project to address the main objectives defined. However, it makes sense to refer some methodological options and discuss their justifications to later describe the articles produced.

4. METHODOLOGICAL CONSIDERATIONS

For all research studies, it was necessary to make carefully reflected and evidence-based decisions regarding the methodology performed. Since some of these options were not fully justified in the articles of this thesis, a detailed description of the missing information is presented in the following sub-sections.

4.1. Systematic review

Considering the need to standardize the measurement of poststroke sensorimotor recovery of the ULs based on a valid healthy reference (Kwakkel et al., 2017), and to support our methodological decisions on scientific evidence, we have chosen to conduct a systematic review of methodological considerations for kinematic analysis of ULs in healthy and poststroke adults. Since, according to Bernhardt *et al*. (2016), insufficient attention has been paid to the recruitment and stratification of poststroke patients, and the influence of factors such as age and sex on healthy movement patterns has been undervalued, we decided that one of the aspects that we would analyse would be the characterization of the healthy and poststroke samples, i.e., the information collected and presented about these participants. For poststroke adults, we analysed whether the information collected was the recommended by SRRR (Kwakkel et al., 2017). Furthermore, as according to Ozturk *et al*. (2016), there are other major methodological factors upon which the kinematic analysis of the ULs depends, we decided to further analyse these factors: motion capture systems, motor tasks and the kinematic metrics extracted. To make reading easier, we split the review into two parts.

4.2. Study designs and participants

Study design and sample of the third and fourth articles were the same. These studies were cross-sectional observational studies since their goal was to describe kinematic strategies used by healthy adults. Sample was recruited for convenience from a population of students and teaching and non-teaching staff from the Polytechnic of Porto and the University of Porto (n=54003), contacted through e-mail; on this e-mail, people were informed about the study and invited to participate by fulfilling a characterization and inclusion/exclusion criteria selection questionnaire (appendix III). Two hundred and seventeen subjects answered the questionnaire, and sixty-three of whom were recruited since they fit the criteria to participate in this study (a detailed description of this process is displayed in figure 1).

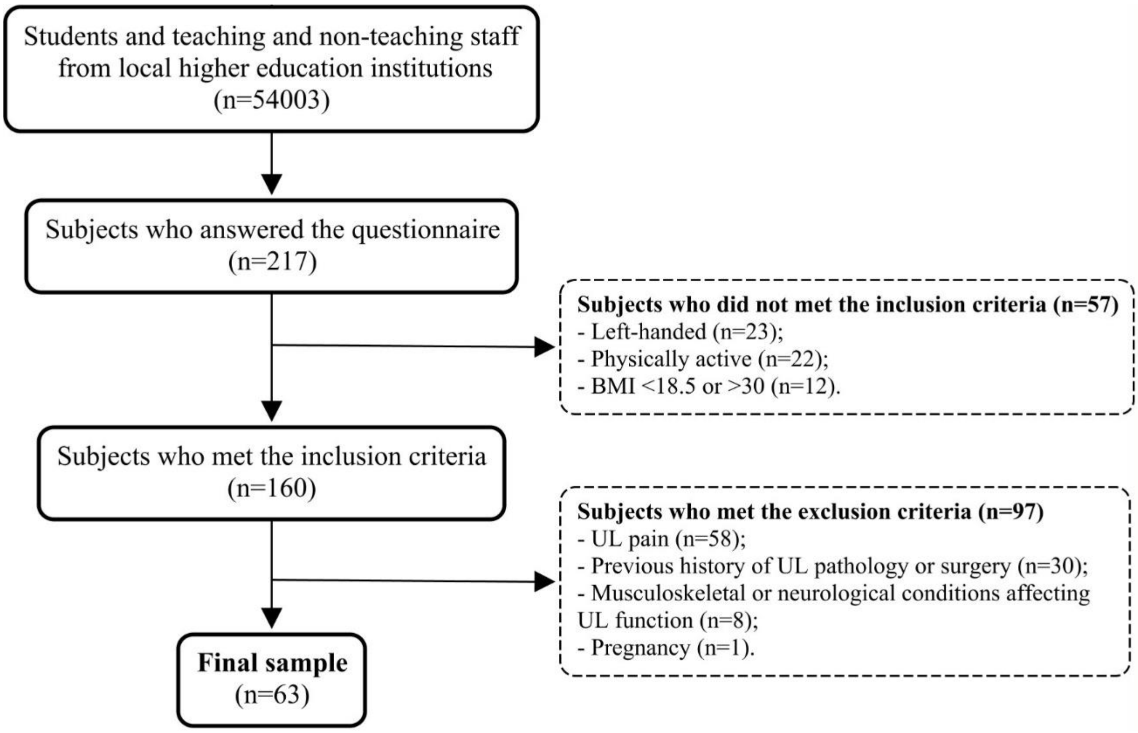


Figure 1. Healthy sample diagram

The inclusion and exclusion criteria of healthy adults were defined to meet the objective of studying the influence of age, sex, BMI and dominance factors; to allow that the characteristics of healthy adults matched as much as possible to those of most poststroke adults; but also to ensure the highest quality of movement capture. Thus, as the incidence of stroke in Europe is higher between 40 and 80 years old and the number of young adults having stroke is increasing (Bejot et al., 2016), we considered it appropriate to include healthy adults with ≥30 years old. As most poststroke survivors experience low levels of physical activity (Field, Gebruers, Shanmuga Sundaram, Nicholson, & Mead, 2013; Fini, Holland, Keating, Simek, & Bernhardt, 2017), we chose to select healthy adults with an insufficient physical activity level, according to Sedentary Behaviour Research Network (2017) (Tremblay et al., 2017). We assessed the level of physical activity through the International Physical Activity Questionnaire (IPAQ)

(Craig et al., 2003). As there is a higher proportion of right-handed than left-handed subjects worldwide (Llaurens, Raymond, & Faurie, 2009) and handedness may be associated with different patterns of neural activation of motor system (Pool, Rehme, Fink, Eickhoff, & Grefkes, 2014), we chose to include only right-handed adults. To ensure correct identification of anatomical references for placement of movement capture system markers, we excluded individuals with obesity. We excluded adults with current or previous history of UL pathology or surgery, as well as UL pain and pregnancy, since these conditions may affected UL function (Finley, Combs, Carnahan, Peacock, & Van Buskirk, 2012; Kim et al., 2014; Murphy et al., 2011; Patterson et al., 2011).

In the fifth study, we analysed poststroke adults, through a longitudinal observational case series study. We have chosen a case series because it is ideal for studying heterogeneous cases as those of poststroke patients and because it allows better characterization and analysis of their results according to their specific characteristics (Carey & Boden, 2003). Thus, it was possible to include poststroke patients with different demographic characteristics, such as age, and different stroke characteristics, such as initial severity and location, and to raise pertinent questions regarding the possible influence of these various characteristics on UL motor recovery. We chose to analyse motor performance at two key moments of poststroke recovery - the early subacute phase and the beginning of chronic phase - as in the first moment the movement pattern results mainly from the spontaneous recovery process (Carrera & Tononi, 2014; Grefkes & Fink, 2011; Ward & Cohen, 2004), and in the second moment the neural network re-organization processes seems to be already matured (Karnath & Rennig, 2017; Ward & Cohen, 2004). Therefore, the analysis of these two moments may allow observing the evolution of motor performance towards restitution or compensation. We chose to exclude patients with severe UL sensorimotor impairment, as they would have extreme difficulty in performing the proposed motor tasks and this would cause frustration and could negatively affect their recovery.

4.3. Motion capture system

Our initial objective was to assess the motor performance of poststroke adults in a hospital or clinical setting. However, when we tested the possibility of using portable motion acquisition systems, we faced difficult problems to solve such as the need to adopt an anatomical position in the calibration process (requirement impossible for poststroke adults), as well as the considerable lack of accuracy in motion detection. For that reason, we decided to use a visual marker-based optoelectronic system (with passive markers), since they are often considered the gold standard in the kinematic analysis because of their high accuracy and reliability (de los Reyes-Guzmán et al., 2014; Ozturk et al., 2016) and they are used as reference for comparisons with other equipments (Vilas-Boas Mdo & Cunha, 2016). However, this decision made it impossible to assess poststroke adults in the clinical setting, due to the large setup volume and consequent difficulty in transportation. Therefore, assessments of both healthy and poststroke adults were performed in the laboratory.

Prior to each recording session the camera system was calibrated with a measurement volume of approximately 8 m^3 and a maximum acceptable error of 0.8 mm.

4.4. Normalization of the experimental setup to anthropometric characteristics

According to our systematic review (Mesquita, Pinheiro, Velhote Correia, & Silva, 2019) only one of the studies that kinematically analysed the UL between 2007 and 2017 (Kim et al., 2014), adjusted the experimental setup to the anthropometric characteristics of each individual. This adjustment (i.e. normalization) is important to ensure that experimental setup is not the responsible for variability in the kinematic metrics analysed. Both variations in the adopted position and the location of the target can create this variability. There are infinite ways of sitting: straight, diagonally, high or low, far into the seat or toward the edge, etc. Different sitting postures clearly affect motor activity of neck, trunk and scapulae (Caneiro et al., 2010; O'Sullivan et al., 2006; O'Sullivan et al., 2002), which are the biomechanical foundation of UL movement. In this study, we normalized the height of the hydraulic gurney and the depth of the base of support, considering the length of the leg and femur of each participant, respectively. As for the target location, it is also known that the variation of distance, for example, affects the movement duration (Fitts, 1954) and trunk displacement (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002). Therefore, we normalized the switch and drinking glass position. The lamp and the drinking glass were placed on a table, whose height was adjusted to the olecranon's height of each patient and at a distance of ipsilateral hip equal to the length between the acromion and the trapezius-metacarpal joint, in the sagittal plane. We chose the hip rather than the acromion as a reference to determine target distance, since hip position in space remains stable throughout the experimental procedures, regardless of the participant's postural control.

4.5. Upper body biomechanical model

To create our upper body biomechanical model comprising both ULs, trunk and pelvis, we used Visual3D v6.01.02 (C-Motion, Inc., Germantown, USA). All modelling was performed according to appropriate C-motion recommendations (C-Motion, 2017). Pelvis was modelled according to the CODA model, with the markers RASIS, LASIS, RPSIS and LPSIS. For the trunk modelling was created a virtual marker (RTA_ORIGIN) whose position was created taking into account the center of mass of the pelvis, with an offset of 100% of the segment length in the posterior position and 5% in the distal (upward, towards the head). This virtual marker was used as the proximal joint center of the trunk, while the right acromial marker (RAC) was used to define the lateral portion of the trunk and the left acromial marker (LAC) the medial portion of the trunk. Markers C7, IJ and PX were used as tracking markers. The right and left shoulder joint center (RT_SHOULDER/LT_SHOULDER, respectively) was approximated as a negative vertical offset of the acromion marker, corresponding to the value of the marker diameter and 17% of the distance between the acromions (RAC and LAC). The humerus was then modelled as having a proximal origin in this virtual marker and a distal limit defined by the lateral and medial markers (RLELB, RMELB, LLELB, LMELB). The elbow joint was defined as the midpoint between the elbow markers (RLELB / RMELB, LLELB / LMELB), which was used to define the proximal point of the radius-ulna complex, and its distal point was laterally defined by the marker of radius (RRAD, LRAD) and medially by the marker of ulna (RULN, LULN). The hand segment was proximally originated from the wrist joint center, defined as the midpoint between the RRAD and RULN markers, and the distal limit was defined laterally by the lateral hand marker (RLH, LLH) and medially by the medial marker (RMH, LMH). In all segments of the ULs, distal anatomical markers were also used as tracking markers as there were no additional markers. In the case of hand, where there were additional markers (RTHUMB and RINDEX), these were not used as tracking markers, since the fingers show movement independent of the hand (defined here as the set of metacarpals).

4.6. Kinematic metrics

To select the set of kinematic metrics, we based on our systematic review and on the literature review of de los Reyes-Guzmán *et al*. (2014), about quantitative assessment based on kinematic measures of functional impairments during UL movements. In our systematic review (Mesquita, Fonseca, Pinheiro, Velhote Correia, & Silva, 2019) we saw that most authors analysed “end-point kinematics” or “joint kinematics”, of which “movement time,” “peak velocity,” “number of movement units (velocity peaks),” “joint angles of shoulder and elbow,” and “trunk displacement” were the most studied. However, we questioned whether their analysis would be sufficient to improve the understanding about the mechanisms driving motor recovery and to differentiate restitution from compensation. Thus, considering that end-point and joint kinematics include a set of metrics that quantify different motion characteristics that may be relevant to this knowledge, we sought to make a selection of metrics that would quantify as many motion characteristics as possible: speed, efficiency, smoothness, control strategy, hand aperture for grasp and release, functional multi-joint angles and compensation. We chose to analyse these metrics in each phase of the tasks, since each phase contains different motor skills.

To quantify speed, we selected absolute and relative durations and mean and peak velocities, according to de los Reyes-Guzmán *et al.* (2014). Usually, a decrease in absolute and relative durations and an increase in mean and peak velocities are attributed to a better UL function within a given task (de los Reyes-Guzmán et al., 2014).

To quantify movement efficiency, we chose the index of curvature (also known as “hand path ratio”), since, according to Lang *et al.* (2005) an efficient movement moves directly to the target without extraneous or abnormal trajectories. It is a measure of how directly the hand moves toward the target computed as the ratio between the length of the real subject's hand path and the length of the theoretical or desired trajectory. Although this metric has been frequently used in literature only during reaching movements (de los Reyes-Guzmán et al., 2014), we considered relevant to calculate it also in the other phases.

To quantify smoothness, we selected number of movement units (also known as “number of velocity peaks”) since this metric was applied frequently in poststroke patients (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; van Dokkum et al., 2014; Wagner, Rhodes, & Patten, 2008). With the presence of movement disorders, the velocity peak number increases resulting in a less smooth movement. If any motor recovery occurs, the velocity profile of the hand movement must present less peaks resulting in a smoother movement (Rohrer et al., 2002).

To quantify control strategy we used time to peak velocity, according to de los Reyes-Guzmán *et al.* (2014). This measure allows to analyse the duration of the hand's acceleration and deceleration periods toward the target, which are often changed in the presence of movement disorders and are often responsible for the presence of dysmetria (de los Reyes-Guzmán et al., 2014).

To quantify hand aperture for grasp and for release, we select the maximum magnitude of hand aperture and the relative instant of hand aperture, according to Patterson *et al.* (2011). According to Castiello (2005), the size of pre-shaping of the fingers for grasping an object increases to a maximum and then is reduced to match the size of the object. The moment of maximum hand aperture occurs during the final-slow approach phase (Shumway-Cook & Woollacott, 2017). Although it is recognized that poststroke patients have difficulty in releasing objects (Seo, Rymer, & Kamper, 2009), to our knowledge, no study has kinematically analysed this specific impairment. In order to assess this behavior, we chose to use the same selected kinematic variables for the assessment of the hand aperture to grasp.

To quantify functional multi-joint angles, we chose to analyse joint angles in clinically relevant planes of the main UL joints in each phase transition, to know which joint angles are intended to be achieved in the end of each phase, i.e. in each motor ability. Despite the well-known fact that scapular motion is a vital component of shoulder function, calculation of shoulder joint kinematics using 3D UL motion analysis is usually carried out with the shoulder considered as a virtual thoraco-humeral joint. The main obstacle to performing an individual assessment of scapula-thoracic and gleno-humeral joints is the difficulty in finding a valid and reliable method to record scapular motion, since marker based techniques are subject to inaccuracies relating to the placement of markers or soft tissue artefacts (Lempereur, Brochard, Leboeuf, & Rémy-Néris, 2014). For these reasons, scapula motion was not analysed.

Finally, to quantify compensation, we used trunk displacement since this variable has been widely used for this purpose (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011). However, in addition to assessing its displacement in the sagittal plane, we also considered of relevance the study of its displacement in the frontal and transverse planes, considering its three-dimensional movement. Furthermore, we analysed trunk displacement in each phase rather than in the total task, as it is important to understand the behavior of trunk displacement according to the motor skill performed by the UL.

4.7 Statistical analysis

The statistical procedures of this work followed a logical and structured order of importance. Firstly, the descriptive statistics was used to present measures of central tendency and also frequency distribution for probabilities of demographic, anthropometric and kinematic data of healthy and poststroke adults.

Inference tests were used for specific comparisons that could point out possible differences between groups of subjects or factors. In this case, to understand if age, sex, hand dominance and/or BMI exerted effect on kinematic strategies of daily activities.

For the third and fourth articles, a Multifactorial Analysis of Variance (MANOVA) allowed to identify the effect of specific factors (age, sex, dominance and BMI) in the kinematic metrics of drinking and turning on the light tasks, and to extrapolate the results. According to the recommendations for age categories division of poststroke patients (Kwakkel et al., 2017), two major age categories were created (30-55; 56-74). Although the authors of these recommendations did not explain this division, it was possibly based on the exponential increase in stroke incidence from 55 years of age (Bejot et al., 2016).

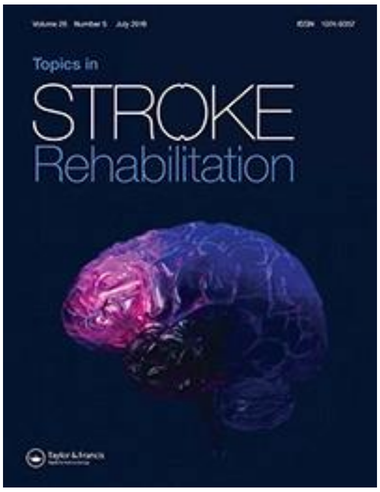
In the fourth article we also used a MANOVA for repeated measures, to determine whether there were any difference in kinematic metrics of healthy adults between drinking and turning on the light tasks.

In the fifth article, as we aimed to understand if the kinematic strategies presented by poststroke adults were different from those used by the healthy sample, we calculated the confidence intervals of 99% of the kinematic variables of healthy adults. This range of values ensures the true mean of healthy population, with 99% certainty (du Prel, Hommel, Röhrig, & Blettner, 2009; Gardner & Altman, 1986; Sim & Reid, 1999). If poststroke adults present different values of this range, this procedure can suggest possible kinematic alterations associated with stroke.

5. ACCEPTED AND SUBMITTED ARTICLES

The first two articles presented are the two parts of a systematic review already published, regarding methodological considerations for kinematic analysis of ULs in healthy and poststroke adults. The specificities of sampling and motor tasks, as well as the motion capture systems and kinematic metrics used in this specific kinematic analysis were review in the first and second parts, respectively. The third article refers to the analysis of kinematic ULs strategies of healthy adults during drinking task. The article that follows, aimed to compare the kinematic strategies used by the ULs of healthy adults in a less difficult ADL (turning on the light) with those that are used in a more difficult ADL (drinking). Subsequently, the fifth study analyses the kinematic strategies of both ULs of poststroke adults in the early sub-acute phase and in the beginning of chronic phase, through a case series. All articles are fully presented in this section. The numbering of tables and figures are restarted in each article.

<u>Article I</u> - Methodological considerations for kinematic analysis of upper limbs in healthy and poststroke adults. Part I: A systematic review of sampling and motor tasks



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ABSTRACT

Background and Purpose: The purpose of this study was to review the methods used to analyse the kinematics of upper limbs (ULs) of healthy and poststroke adults, namely specificities of sampling and motor tasks.

Summary of review: A database of articles published in the last decade was compiled using the following search terms combinations: (“upper extremity” OR “upper limb” OR arm) AND (kinematic OR motion OR movement) AND (analysis OR assessment OR measurement). The articles included in this review (1) had the purpose to analyse objectively a three-dimension kinematics of ULs, (2) studied functional movements or activities of daily living (ADL) involving uppers limbs, and (3) studied healthy and/or poststroke adults. Fourteen articles were included (four studied a healthy sample, three analysed poststroke patients, and seven examined both poststroke and healthy participants).

Conclusion: Most of the recommended demographic and stroke information, such as some preexisting conditions to stroke, initial stroke severity, and stroke location, were not collected by all or most of the articles. Time poststroke onset was presented in all articles but showed great variability. Few articles identified anthropometric characteristics and adjusted task environment to them. Most of the samples were composed mainly by males and had a low mean age, which does not represent poststroke population. Most articles analysed “functional movements”, namely simulations of ADL.

Implication of key findings: Future research should identify the recommended information to allow an adequate stratification. Acute phase after stroke, real ADL with different complexities, and ipsilesional UL should be studied.

Keywords: Upper extremity, kinematic assessment, stroke, healthy adults, demographic information, stroke information, activities of daily living.

1. Introduction

Recovery and a return to a full life following stroke are the main goals for stroke survivors, their families and caregivers, and health professionals (Walker et al., 2017). However, more than 80% of stroke patients experience acute sensorimotor dysfunction of the contralesional upper limb (UL), which becomes chronic for more than 40% of the patients (Cramer et al., 1997). According to the Stroke Recovery and Rehabilitation Roundtable (SRRR), the ability to understand the recovery mechanisms and to devise better treatments is hampered by the lack of a standardized approach to measurement in stroke recovery research (Kwakkel et al., 2017). Insufficient attention has also been paid to patient's recruitment and stratification (Bernhardt et al., 2016). The magnitude of change and likelihood of achieving clinically meaningful improvement in response to specific therapies will depend on age, stroke severity, physical and other factors including pre-existing comorbid conditions (Kwakkel et al., 2017). The respective contributions of these factors have yet to be fully understood (Kwakkel et al., 2017).

Recently, the SRRR presented the results of a consensus meeting about measurement standards and information they suggest should be collected in all future stroke recovery trials (Kwakkel et al., 2017). Recommendations for demographic and stroke information include: age, sex, medical history, stroke severity, type and location, among others (Kwakkel et al., 2017). Moreover, recovery trials should start early poststroke, and include both core clinical measures (e.g. the National Institute of Health Stroke Scale (NIHSS) and the Fugl-Meyer Assessment (FMA)) and kinematics assessed serially at standard intervals poststroke (Kwakkel et al., 2017). While clinical measures can detect change, they cannot differentiate restitution from compensation. Kinematics' parameters are presented as one of the best ways for this purpose and to improve the understanding about the mechanisms that drive motor recovery (Kwakkel et al., 2017). However, a core set of kinematic outcomes needs to be established (Kwakkel et al., 2017).

In fact, in the last decade, three-dimensional (3D) kinematics of upper limbs (ULs) of healthy adults and neurological patients, mostly after stroke, were studied in order to quantify movement objectively and accurately (de los Reyes-Guzmán et al., 2014). The 3D systems have been shown to be highly accurate and able to capture simultaneous multi-segmental movement characteristics of human motion, providing detailed knowledge not available through conventional two-dimensional and observational analyses (Rutherford & Kozey, 2014). Can the mentioned studies be used as reliable references? Have they complied with the recent recommendations regarding the collection of demographic and stroke information? In parallel, were the analysed healthy individuals' characteristics matching the poststroke individuals to provide a database that could be used as a reference? Similarly to poststroke adults, it is necessary to analyse the information that was collected about healthy/control participants, and its characteristics, to check if they can be used as a reference for stroke rehabilitation and research. Therefore, in this review, we explore the collected information about the samples including healthy participants (isolated and/or as a control) and poststroke adults.

There are also four major factors on which kinematic analysis of ULs depends, which should not be overlooked: (a) motion capture systems (b) movement category, i.e. motor tasks, (c) kinematic metrics extracted, (d) and interpretation of these kinematic metrics (Ozturk et al., 2016). Considering the manifested urgency in presenting additional recommendations for the use of kinematic measures in stroke recovery and rehabilitation research (Kwakkel et al., 2017), we have also reviewed these factors. To make reading easier, we split this review into two parts. So, in this first part, besides sampling characteristics, we review the motor tasks used to analyse the ULs kinematics.

The motor tasks generally used to study the function of ULs can be categorized into functional movements (reaching movements and path drawing) and activities of daily living (ADL) (de los Reyes-Guzmán et al., 2014; Ozturk et al., 2016; van Tuijl et al., 2002). Several authors (de los Reyes-Guzmán et al., 2014; Kim et al., 2014; Murphy et al., 2012; Murphy et al., 2011) defend that the analysis of goal-oriented tasks, such as performing an ADL, increases the validity of studies. However, this may complicate the kinematic analysis of ULs since, unlike lower limbs, they are involved in several important ADL (van Andel, Wolterbeek, Doorenbosch, Veeger, & Harlaar, 2008). Furthermore, most stroke survivors are far from performing any ADL due to impairments in prehensile function (Nowak, 2008). Therefore, what kind of movement category is being studied and what is its complexity level?

Based on these questions, the aim of this study was to review and discuss the methods used to analyse the kinematics of ULs of healthy and poststroke adults, namely the specificities of sampling and performed motor tasks.

2. Methods

The study was conducted using the “PRISMA guidelines for a Systematic Review” (“Preferred Reporting Items for Systematic Reviews and Meta-Analysis”) (Moher, Liberati, Tetzlaff, Altman, & Group, 2009).

2.1 Research questions

The two main research questions in this study were:

1- What was the collected information, and its characteristics, about stroke and healthy/control samples found in literature that analysed the ULs kinematics?
2- What were the motor tasks performed in these same studies and in which movement category are they included?

2.2 Search strategy

Two reviewers performed an electronic search on PubMed database and the resource aggregator B-on, namely using the EBSCO EDS interface, to find all the articles published between January 1 2007 and December 31 2017 on the topic of UL kinematic analysis in healthy and poststroke adults. The following search terms combinations were used: (“upper extremity” OR “upper limb” OR arm) AND (kinematics OR motion OR movement) AND (analysis OR assessment OR measurement). The search terms were limited to titles of available full scientific articles, published in academic journals and written in English. The reference lists of all articles were also scanned to identify other potential eligible articles.

2.3 Inclusion and exclusion criteria

The articles included in this review: (i) had the purpose to analyse objectively 3D kinematics of ULs; (ii) studied functional movements of ULs, or ADL involving ULs (according to van Tuijl *et al.* (2002)), clearly described; and (iii) studied healthy living adult (>19 years old) humans and/or adult humans with stroke sequelae. The articles excluded from this review: (i) analysed a single UL joint rather the UL itself, since the recommendations (Kwakkel et al., 2017) suggest UL assessment rather than isolated joints; (ii) studied athletes, to eliminate the sport gesture influence on the UL movement; (iii) used robots, exoskeletons or virtual realities, to study more realistic contexts; (iv) were meta-analyses, reviews, case reports, pilot studies, technical notes or studies published as conference proceedings.

2.4 Assessment of methodologic quality

The articles included in this systematic review were evaluated using a quality index proposed by Downs and Black (Downs & Black, 1998). West *et al.* (West et al., 2002) identified the Downs and Black checklist as being consistent with 18 other recommended quality assessment systems. Studies meeting <60% criteria were considered low quality, ≥60%-<75% moderate quality, and ≥75% high quality. The two searching reviewers independently performed the quality assessment for each of the included articles. Consensus regarding the quality index score for each article was achieved by both authors.

2.5 Data extraction

Data from the included articles were extracted by one reviewer and then checked by a second reviewer using a data extraction table (table 2) which identified: author identification, year of publication, sample used, motor tasks and quality index score.

3. Results

3.1 Search yield

The search strategy revealed 471 results and 3 other articles were identified through the reference lists (table 1).

Table 1- Number of articles collected from PubMed and B-on.

Search terms	*PubMed*	*B-on*	*References*
"upper extremity" OR "upper limb" OR arm AND kinematics OR motion OR movement AND analysis OR assessment OR measurement	20	451	3

After an initial examination, 329 were rejected as copies of the same article; the remaining 145 articles were then reviewed by the two independent reviewers. From these, 86 were not included since they: (i) studied sport gestures, passive movements, purposeless or unclear movements; (ii) and/or examined children, animals, corpses or other pathologic conditions. From the 59 included articles, 45 were excluded as they: (i) analysed only one joint of the UL; (ii) were in athletes; (iii) used robots, exoskeletons or virtual realities; (iv) and/or were meta-analyses, reviews, case reports, pilot studies, technical notes or studies published as conference proceedings.

A total of 14 articles were considered in the current review as shown in Figure 1, of which four included a healthy sample (Aizawa et al., 2010; Chen, Xiong, Huang, Sun, & Xiong, 2010; Jacquier-Bret, Gorce, Motti Lilian, & Vigouroux, 2017; van Andel et al., 2008), three studied poststroke patients (Murphy et al., 2013; Murphy et al., 2012; Wagner et al., 2008) and seven comprised both a stroke group and a healthy/control group (Finley et al., 2012; Kim et al., 2014;

Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014).

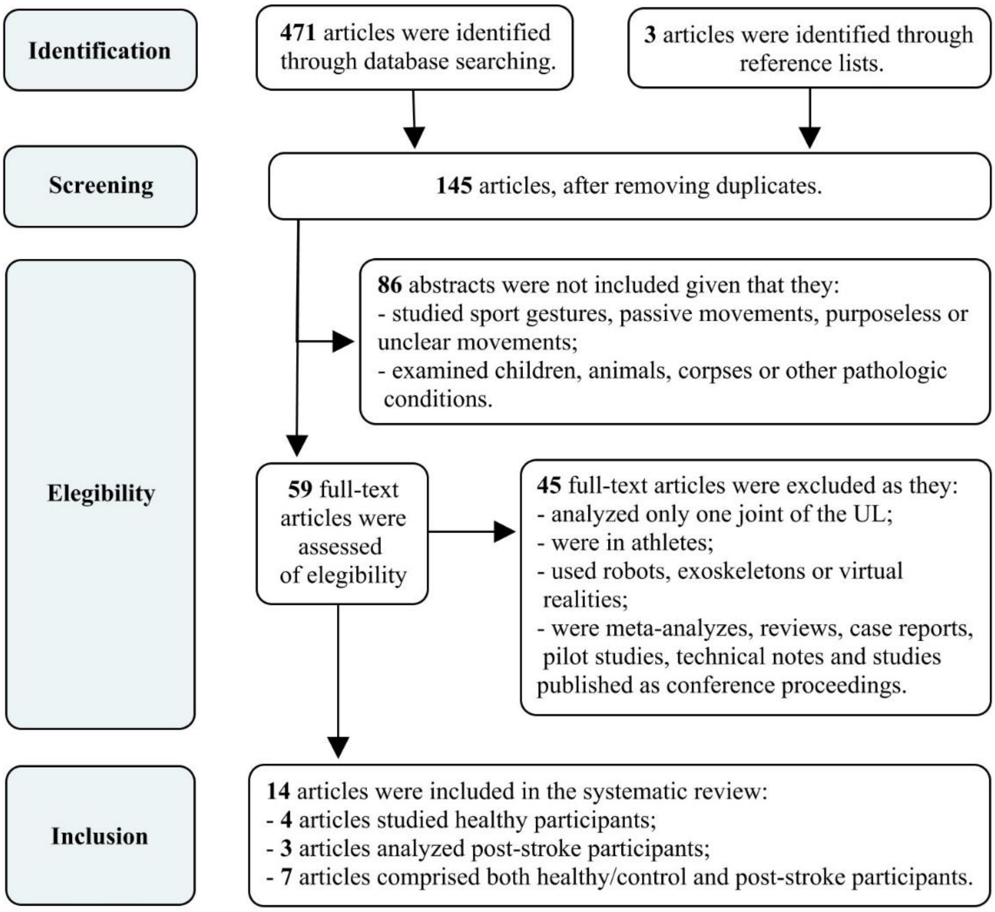


Figure 1. Review selection and exclusion criteria.

3.2 Collected information about samples

3.2.1 Samples including healthy participants (isolated and/or as a control)

From the articles comprising healthy participants, both singly and as a control group for poststroke patients, only one (Ozturk et al., 2016) did not present demographic or any other information about these participants. All other ten articles presented information about sex and nine of them about age (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Kim et al., 2014; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009; van Andel et al., 2008; van Dokkum et al., 2014) and handedness (Aizawa et al., 2010; Chen et al., 2010;

Finley et al., 2012; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009; van Andel et al., 2008). Presence or clinical history of orthopedic or neurologic disorders that would affect UL performance were collected by authors of six articles (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Jacquier-Bret et al., 2017; Patterson et al., 2011; van Dokkum et al., 2014). Few articles presented anthropometric information, namely height (Aizawa et al., 2010; Chen et al., 2010; Kim et al., 2014), weight (Aizawa et al., 2010; Chen et al., 2010; Kim et al., 2014) and body mass index (BMI) (Aizawa et al., 2010), and even less checked UL range of motion (Chen et al., 2010), active shoulder elevation (Finley et al., 2012), visual acuity (Finley et al., 2012) and ability to follow verbal instructions (Finley et al., 2012).

Males were the most studied in six studies (Finley et al., 2012; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2011; Thies et al., 2009; van Andel et al., 2008). A comparison of the kinematic metrics between both sexes was not found.

Five articles (Aizawa et al., 2010; Chen et al., 2010; Kim et al., 2014; van Andel et al., 2008; van Dokkum et al., 2014) were performed with young adults, whose mean age ranged from 23.0 to 32.5 years old, and four articles (Finley et al., 2012; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009) included older participants, whose mean age ranged from 57.2 to 60.3 years old. A comparison of the kinematic metrics between age groups was not found.

The majority of the articles (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Jacquier-Bret et al., 2017; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009) studied only right-handed subjects, and another two (Kim et al., 2014; van Andel et al., 2008) included mainly right-handed subjects. The latter did not analyse the kinematic metrics according to the handedness.

Of the studies that collected anthropometric data, only one (Kim et al., 2014) used this information to adjust and normalize the experimental set.

Table 2 – Sample characteristics, motor tasks and quality index score.

Reference	*Sample characteristics*		*Motor task(s)*	*Quality index score (%)*
van Andel *et al.*, 2008	***Healthy participants*** ▪ n=10, (4F, 6M) ▪ Age: 28.5 ± 5.7 years old ▪ Handedness: right-handed (9) and left-handed (1)		(i) Hand to the contralateral shoulder; (ii) Hand to mouth/drinking; (iii) Combing hair (hand to the fore head and towards the neck); (iv) Hand to back pocket. *All tasks were performed with right UL. Subjects were asked to copy the movements of the instructor standing in front of them.*	34%
Wagner *et al.*, 2008	***Poststroke participants*** ▪ n=14 (3F, 11M) ▪ Age: 59.9 ± 14.6 (22-82) years old ▪ Time poststroke onset: 14.0 ± 6.5 months ▪ FMA total: 89.4 ± 10.2 ▪ FMA-UE motor: 34.7 ± 9.0 ▪ FMA-UE shoulder/elbow: 16.8 ± 6.5 ▪ MAS: 0.67 ± 0.53		(i) Reach forward toward a 2.2-cm-wide piece of tape located at the superior end of a 0,5-cm-diameter vertical rod attached to a solid circular base; (ii) Four different reaching tasks produced by the combination of 2 target heights (low and high [109 and 153 cm form the floor, respectively]) and 2 instructed speeds of movement (self-selected and fast as possible). *The target was positioned directly in front of the "affected" (contralateral to the lesion) shoulder at 110% of arm's length. Participants performed the tasks seated in a straight-back chair. The trunk was stabilized to the back of the chair to minimize compensatory trunk movements.*	63%
Thies *et al.*, 2009	***Poststroke participants*** ▪ n=6 (2F, 4M) ▪ Age: (33-83) years old ▪ Time poststroke onset: (6– 48) months ▪ Handedness: right-handed (6) ▪ Affected side: right (3), left (3) ▪ Motricity index: 63-76/100 ▪ Ashworth scale: 0-3 ▪ Light Touch Discrimination (Wrist, Hand): 0-6/6 ▪ Movement Detection (shoulder, elbow, wrist and thumb): 3-6/6	***Healthy control participants*** ▪ n=6 Age, sex and right/left hand dominance of each control participant corresponded to his/her respective poststroke participant.	(i) Unilateral task: Drinking from a glass. Poststroke participants performed the task with their affected UL, and controls had to use the same UL as their corresponding match; (ii) Bilateral task: moving a plate. Manipulation of the plate contained a small upwards lift of the plate in front of the torso, followed by a sideways translation of the plate towards the side where the plate was then lowered onto the table. *The location of each object, at a self-reported comfortable distance to the subject, was likewise marked on the table's cover. Care was taken that the object was placed within a distance that did not require engagement of the torso during task performance. Both tasks were performed at a self-selected comfortable speed.*	69%

(continued)

Table 2. (Continued)

Reference	Sample characteristics		Motor task(s)	Quality index score (%)
Aizawa *et al.*, 2010	***Healthy participants*** ▪ n=20 (10F, 10M) ▪ Age: 23 ± 5 (18-34) years old ▪ Height: 166 ± 10 (149-182) cm ▪ Weight: 61 ± 11 (47-78) kg ▪ Body mass index: 22 ± 2.3 (17-27) kg/m ▪ Handedness: right-handed (20)		Bilateral 16 movement tasks related to personal care/hygiene and diet/food preparation: (i) touching the ipsilateral axilla; (ii) touching the opposite axilla; (iii) touching the mouth; (iv) touching the ipsilateral ear; (v) touching the opposite ear; (vi) touching the forehead; (vii) touching the perineum; (viii) touching the back; (ix) fastening a button at neck level; (x) fastening a button at navel level; (xi) washing the face; (xii) putting on a necklace; (xiii) combing air; (xiv) eating with a spoon; (xv) pouring water into a glass; (xvi) drinking with a glass. *An instructor explained the basic pattern of the movement tasks. All tasks were performed at a comfortable speed.*	56%
Chen *et al.*, 2010	***Healthy participants*** ▪ n=10 (0F, 10M) ▪ Age: 25 ± 3 years old ▪ Height: 170 ± 10 cm ▪ Weight: 65.2 ± 4 kg ▪ Handedness: right-handed (10)		Tasks (i), (ii) and (iii) of van Andel *et al*.. *Subjects were asked to follow the movements of the instructor standing in front of them.*	50%
Murphy *et al.*, 2011	***Poststroke participants*** ▪ n=19 ▪ Age: 61 ± 11.1 (41-79) years old ▪ Time poststroke onset: 18.9 ± 16.4 months ▪ Stroke type: infarct (14) and hemorrhage (5) ▪ Stroke side: right (12), left (7) ▪ Handedness: right-handed (19) ▪ FMA-UE: 53,4 ± 8,7 (39-64) ○ Moderate arm impairment: 10 ○ Mild arm impairment: 9 ▪ Sensation: 3-12/12 ▪ Passive range of movement: 17-24/24 ▪ Pain: 12-24/24	***Healthy control participants*** ▪ n=19 (9F, 10M) ▪ Age: 57.3 (41-78) years old ▪ Handedness: right-handed (19)	(i) Drinking. *Participants were seated on a 46-cm high, straight-back chair in front of a 74-cm high table. The drinking glass was 7 cm in diameter and 9.5 cm high and was filled with 100 mL water. It was placed 30 cm from the table edge in the midline of the body. Participants were instructed to sit against the chair back during the whole task, but the sitting position was not restrained, and compensatory movements were allowed if needed. Participants performed the drinking task starting randomly with their right or left arm. They were instructed to initiate the drinking task at a comfortable self-paced speed.*	72%

(continued)

Table 2. (Continued)

Reference	Sample characteristics		Motor task(s)	Quality index score (%)
Patterson *et al.*, 2011	***Poststroke participants*** ▪ n=18 (5F, 13M) ▪ Age: 67.6 ± 8.1 (47-78) years old ▪ Time poststroke onset: (7-174) months ▪ Stroke type: ischemic (18) ▪ Affected side: right (7), left (11) ▪ Stroke location: middle cerebral artery (6), striatocapsular (2), lacunar (2), middle/posterior cerebral artery (1), medullary/brainstem (1), medial medullary (1), posterior cerebellar (1), basal ganglia (1), posterior periventricular white matter (1), pontine (1), brainstem lacunar (1). ▪ FMA-UE: 27-58 ○ Severe arm impairment: 9 ○ Moderate arm impairment: 8 ○ Mild arm impairment: 1	***Healthy control participants*** ▪ n= 9 (8F, 1M) ▪ Age: 57.2 ± 6.7 years old ▪ Handedness: right-handed (19)	(i) Reach and touch a piece of tape affixed to the table at midline at two different speeds: at a self-selected comfortable pace, and as quickly as possible. (ii) Reach and grasp cylindrical cans of different sizes (208 mm circumference and 270 mm circumference) but of the same weight placed on the table directly in front of the reaching hand.	59%
Finley *et al.*, 2012	***Poststroke participants*** ▪ n=15 (6F, 9M) ▪ Age: 62.4 ± 8.4 (48-76) years old ▪ Time poststroke onset: 74.1 ± 50.1 (12-171.0) months ▪ Side of hemiparesis: right (7), left (8) ▪ FMA-UE: 48.5 ± 18.4 (15-64) ○ Severe arm impairment: 3 ○ Moderate arm impairment: 2 ○ Mild arm impairment: 10 ▪ Handedness: right-handed (15)	***Healthy control participants*** ▪ n= 15 (7F, 8M) ▪ Age: 60.3 ± 10.6 years old ▪ Handedness: right-handed (15)	(i) Reach and touch a target located to left and right of midline, 45º in the horizontal plane and return. *Participants were seated with a cross-chest harness trunk restraint system preventing forward flexion. They were seated at such a height that the extremity resting on the table created a 60-70º humerothoracic angle, with a center of the template at the participant's maximal reaching distance, placed directly in front of the individuals at midline. Movements were performed unilaterally with each UL at a self-selected, comfortable speed and at a fast speed to targets placed ipsilateral to the moving limb and contralateral to the limb. The order of reaching limb, target location and speed movement was randomized.*	75%

(continued)

Table 2. (Continued)

Reference	*Sample characteristics*		*Motor task(s)*	*Quality index score (%)*
Murphy *et al.*, 2012	***Poststroke participants*** ▪ n=30 (15F, 15M) ▪ Age: 66.4 ± 12.8 years old ▪ Time poststroke onset: 2.5 ± 2.4 months ▪ Stroke type: ischemic (18), hemorrhagic (12) ▪ Affected side: right (14), left (16) ▪ FMA-UE: 53.6 ± 9.1 (32-64) ▪ ARAT**:** 47.6 ± 8.8 ▪ ABILHAND: 2.2 ± 1.7		(i) Drinking. *The drinking glass was filled with 100 mL water and placed 30 cm from the table edge in the midline of the body, corresponding approximately to a distance of 80% of arm's length. Participants were sitting in a height-adjustable chair with their back against the chair's back, but the position was not restrained and compensatory movements were allowed if needed. The task was performed at a comfortable self-paced speed, and both arms were tested starting with the nonaffected arm.*	72%
Murphy *et al.*, 2013	***Poststroke participants (subgroup 1)*** ▪ n=27 (12F, 15M) ▪ Age: 64.0 ± 12.9 years old ▪ Time poststroke onset: 9.3 ± 9.4 days ▪ Stroke type: ischemic (26), hemorrhagic (1) ▪ Hemiparesis side: right (13) left (14) ▪ FMA-UE: 60.7 ± 4.7 ▪ ARAT: 55.2 ± 1.9	***Poststroke participants (subgroup 2)*** ▪ n=24 (8F, 16M) ▪ Age: 65.6 ± 10.6 years old ▪ Time poststroke onset: 9.8 ± 10.9 days ▪ Stroke type: ischemic (18), hemorrhagic (6) ▪ Hemiparesis side: right (8) left (16) ▪ FMA-UE: 50.6 ± 9.4 ▪ ARAT: 42.0 ± 7.1	The same task of Murphy *et al*. (2012) but only the affected UL were used.	78%
van Dokkum *et. al*, 2014	***Poststroke participants*** ▪ n=13 (3F, 10M) ▪ Age: 63.9 ± 9.4 (43-81) years old ▪ Time poststroke onset: 21 ± 7 (13-30) days ▪ Stroke type: ischemic (9), hemorrhagic (4) ▪ Damaged hemisphere: right (5), left (8) ▪ Localization: deep/sub-cortical (5), deep+superficial (5), superficial/cortical (3). ▪ Hemiplegia side: left (6) ▪ FMA-UE: (4-62)	***Healthy control participants*** ▪ n=12 (12F, 0M) ▪ Age: 32.5 ± 11.4 years old	(i) "Reach-to-grasp" a 5 cm ball lying on a table placed 20 cm in front and bring the ball to a target location 5 cm from the edge of the table. *The task was executed first with the nonparetic limb, then with the paretic limb. Pace was self-selected. Participants were seated in front of a table at waist height, so that shoulders remained at rest, elbows were flexed 90°, and hands (palms down) could be placed easily at their respective starting positions. Participants' trunks were strapped to prevent potential compensating movements.*	59%

(continued)

Table 2. (Continued)

Reference	Sample characteristics		Motor task(s)	Quality index score (%)
Kim *et al.*, 2014	***Poststroke participants*** ▪ n=16 (3F, 13M) ▪ Age: 49.8 ± 7.3 (15-70) years old ▪ Time poststroke onset: (6-108) months ▪ Impaired UL function: right (8), left (8) ▪ Height: 167.9 ± 3.8 cm ▪ Weight: 67.9 ± 4.2 kg	***Healthy control participants*** ▪ n=32 (15F, 17M) ▪ Age: 25.3 ± 2.4 years old ▪ Height: 168.7 ± 3.9 cm ▪ Weight: 62.0 ± 5.4 kg ▪ Handedness: right-handed (30) and left-handed (2)	(i) Drinking. *Each subject was instructed how to perform the drinking task. All participants were seated at a right angle in a chair with their UL supported on a table. The UL was placed against the trunk and the elbow was flexed at 90°. In every case, the subject-to-table distance was regularly maintained, and the sitting and table heights could be adapted to obtain the same starting position for all participants.*	50%
Ozturk *et al.*, 2016	***Poststroke participants*** ▪ n=3 (1F, 2M) ▪ Age: (55-61) years old ▪ Time poststroke onset: (4-11) months ▪ Hemiparetic side: left (3) ▪ WMFT: 25-71	***Healthy control participants*** ▪ n=2	(i) Reaching movement from neutral position to non-specified location on a table. *Seated subjects were asked to perform natural, self-paced reaching movement. All patients performed the reaching task with their hemi-paretic arm and all normal subjects with their right arm.*	38%
Jacquier-Bret *et al.*, 2017	***Healthy participants*** ▪ n=11 (1F, 10M) ▪ Handedness: right-handed (11)		(i) Achieving a puzzle presented on the touch screen device. Task were performed by right UL. *Subjects were seated against the back of a chair, in front of a touch screen device horizontally placed on a table, with the forearms resting on either side of the device. The centre of the touch screen was at 15 cm from the edge of the table. Two sizes of devices, a 5-inch and a 10-inch touch screen size, were used. For each device, two puzzles with a different number of pieces (9 or 16 pieces) were selected to manipulate the size of the piece of the puzzle. The size of the puzzle pieces is proportional to the screen size and inversely proportional to the number of pieces. Each of the four puzzles (9 or 16 pieces performed with a 5- or a 10-inch touch screen) was repeated five times in a random order.*	53%

Legend: F – Female; M – Male; UL – Upper limb; FMA – Fugl-Meyer Assessment; MAS – Modified Ashworth Scale; ROM – Range of Motion; ARAT – Action Research Arm Test; WMFT – Wolf Motor Function Test

3.2.2 Samples including poststroke patients

A high variety of information had been collected by the authors of articles including poststroke patients. However, just the age and the time poststroke onset were collected by all of them. The mean age ranged from 49.8 (Kim et al., 2014) to 66.7 (Patterson et al., 2011) years old and most articles (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009; Wagner et al., 2008) were carried out during the chronic phase (time after stroke onset ranging from 0.5 to 14.5 years). Two (Murphy et al., 2013; van Dokkum et al., 2014) other articles analyse patients during the acute phase, one (Ozturk et al., 2016) considered both sub-acute and chronic phases, and another one (Murphy et al., 2012) was performed during the sub-acute phase.

Other information gathered by most articles were sex (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014; Wagner et al., 2008), the "hemiparetic side" (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014), the body function and structure through the Fugl-Meyer Assessment - Upper Extremity (FMA-UE) (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008) and previous history of stroke (Finley et al., 2012; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008). Eight (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014; Wagner et al., 2008) articles evaluated mostly males and the left side of body was the most "affected" in four articles (Finley et al., 2012; Murphy et al., 2013; Murphy et al., 2012; Patterson et al., 2011) ("*hemiplegia side", "hemiparetic side" or "impaired arm function"*, according to the authors). According to the FMA-UE, most authors included subjects with mild (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; van Dokkum et al., 2014) motor impairment. Nevertheless, five articles included also participants with severe (Finley et al., 2012; Murphy et al., 2012; Patterson et al., 2011; van

Dokkum et al., 2014; Wagner et al., 2008), and moderate (Finley et al., 2012; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; van Dokkum et al., 2014) motor impairment. Only subjects with a single stroke were included in the studies that accounted this information.

In addition to FMA-UE, other clinical scales were used by some authors, namely the Ashworth Scale (Thies et al., 2009) and its modified version (Murphy et al., 2013; Murphy et al., 2012; Wagner et al., 2008), the Action Research Arm Test (ARAT) (Murphy et al., 2013; Murphy et al., 2012), the ABILHAND (Murphy et al., 2012), the Motricity Index (Thies et al., 2009), the Brunnstrom Motor Recovery Stages (Kim et al., 2014) and the Wolf Motor Function Test (Ozturk et al., 2016).

Presence of problems that could affect the UL function or performance were checked by some authors, namely cognitive decline (Finley et al., 2012; Kim et al., 2014; Patterson et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008), sensory deficits (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009; Wagner et al., 2008), pain (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Wagner et al., 2008), other musculoskeletal or neurological conditions (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011), visuospatial problems (Finley et al., 2012; Thies et al., 2009) and neglect (van Dokkum et al., 2014).

Active (Finley et al., 2012; Patterson et al., 2011; Wagner et al., 2008) and passive (Murphy et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008) range of motion of UL joints as well as the ability to reach forward (Patterson et al., 2011), open the hand (Thies et al., 2009), grasp (Thies et al., 2009) and drink (Murphy et al., 2012; Murphy et al., 2011) with the contralesional UL, at the assessment moment, were also gathered by some authors.

Kim *et al*. (Kim et al., 2014) were the only ones presenting information on height and weight, being the mean height 168 cm and the mean weight 67.9 kg.

The articles that stated handedness of participants (Finley et al., 2012; Murphy et al., 2011; Thies et al., 2009) included only right-handed subjects.

About the stroke, five studies (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; van Dokkum et al., 2014) presented information about its type and only two about its side (Murphy et al., 2011; van Dokkum et al., 2014) and location (Patterson et al., 2011; van Dokkum et al., 2014). Infarct (ischemic stroke) was the predominant stroke type (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; van Dokkum et al., 2014). Murphy *et al*. (Murphy et al., 2011) studied subjects whose stroke side was mostly the right hemisphere and van Dokkum *et al*. (2014) whose stroke side was mostly the left. The articles reporting stroke location used different categories: Patterson *et al*. (2011) categorized according to the vascular territory and most of participants had a stroke involving the middle cerebral artery; and van Dokkum *et al*. (2014) grouped into "*superficial/cortical*", "*deep/sub-cortical*" and "*superficial+deep*" location categories and most of participants had a "*deep/sub-cortical*" or "*superficial+deep*" stroke. No articles have compared kinematic metrics according to stroke location.

Thrombolysis (Murphy et al., 2013) and imaging to confirm stroke (Wagner et al., 2008) were only referred by one article. No study presented information about stroke severity or sub-type, as well as about active hand movement and ability to walk independently at stroke onset.

3.3 Motor tasks

Reviewers included only real ADL in the "ADL" category. Simulations of ADL were considered "functional movements" since they consist of reaching and touching body parts. "Achieving a puzzle presented on the touch screen device" (Jacquier-Bret et al., 2017) was included in the "ADL" category, since interaction with technological devices is increasingly common in daily life.

Eight articles (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Ozturk et al., 2016; Patterson et al., 2011; van Andel et al., 2008; van Dokkum et al., 2014; Wagner et al., 2008) analysed "functional movements", being reach and touch a body part, namely the own mouth and forehead, the most accomplished (Aizawa et al., 2010; Chen et al., 2010; van Andel et al., 2008).

Seven articles (Aizawa et al., 2010; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009) analysed "ADL", specifically tasks related to feeding (Aizawa et al., 2010; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009), and handling, transporting and dropping objects of everyday life (Aizawa et al., 2010; Jacquier-Bret et al., 2017; Thies et al., 2009). Within these sub-categories, the most performed task was drinking (Aizawa et al., 2010; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009).

Motor tasks were performed by only one UL in most articles (Chen et al., 2010; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Andel et al., 2008; Wagner et al., 2008) (the "*affected arm*" in stroke participants (Murphy et al., 2013; Ozturk et al., 2016; Thies et al., 2009; Wagner et al., 2008), and the "*corresponding"* (Thies et al., 2009) or the right (Jacquier-Bret et al., 2017; Ozturk et al., 2016; van Andel et al., 2008) UL in healthy/control participants); six articles (Aizawa et al., 2010; Finley et al., 2012; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009; van Dokkum et al., 2014) evaluated both ULs. Only Thies *et al.* (2009) analysed a bilateral motor task ("*moving a plate*").

4. Discussion

In this systematic review we gathered literature that analysed the kinematics of ULs in order to identify which were (i) the information, and its characteristics, about stroke and healthy/control samples that was being collected, and (ii) the motor tasks/movement categories performed in these same articles. In fact, this information is extremely important as it guides the evidence serving as a basis for stroke rehabilitation and research. Beyond the answers found, this systematic review triggers a reflection on relevant elements to be considered in future studies.

4.1 Collected information about samples

Recently, SRRR recommendations for demographic and stroke information collection were published (Kwakkel et al., 2017). Better knowledge of patients' profiles will help to design better trials in terms of adequate stratification, but also will generate new and better hypotheses about how therapies work and the underlying mechanisms of recovery (Kwakkel et al., 2017). Age, sex, ethnicity, medical history, premorbid function, education, premorbid walking status, and premorbid living arrangements are the recommended demographic information (Kwakkel et al., 2017). “Baseline” stroke severity (through the National Institute of Health Stroke Scale), active hand movement and ability to walk independently at stroke onset, stroke type, sub-type (lacunar / large artery / carotid dissection / undetermined) and location, as well as thrombolysis/reperfusion therapy and imaging are the recommended stroke information (Kwakkel et al., 2017).

About demographic information, only age and sex were accounted by almost all articles included in this review. Some of them also collected medical history. No further recommended demographic information was collected. With respect to their characteristics, most articles with healthy participants presented subjects generally younger than those belonging to poststroke groups. For example, Kim *et al*. (2014) excluded elderly from their healthy-control group “*because they showed many neurological problems*” (although they did not describe which) and because their study *“aimed to build a database of more conventional motions of fine hand movements (…) and to compare differences from the hemiplegic group more accurately*.” Considering the mean age found in this review for poststroke human adults (ranging from 49.8 (Kim et al., 2014) to 66.7 (Patterson et al., 2011) years old) and the findings of another systematic review (Appelros, Stegmayr, & Terént, 2009) (mean age of 68.6 years old among men, and 72.9 years among women), should we be using data from healthy young subjects as a reference/control of poststroke subjects, who are substantially older? Evidence shows that there are changes in postural control and mobility skills, namely in reaching movement time (Welford, 1982; Williams, 1990) and coordination (Fradet et al., 2008; Morgan et al., 1994; Pohl et al., 1996; Vrtunski & Patterson, 1985), with ageing (Shumway-Cook & Woollacott, 2017). Is it reasonable that the reference for the rehabilitation of poststroke subjects comes from healthy young subjects? Do poststroke patients and health professionals intend to achieve a younger adult movement pattern? Taking this as a limitation, we state that studies are needed with healthy older adults analyzing differences between ageing sub-groups, to build an accurate database of more conventional UL movements, and to study the best reference for the rehabilitation of poststroke patients.

Males were the most studied among both healthy and/or poststroke human adults. This finding is in agreement with the fact that stroke is more common among men, although the difference tends to decrease with age (Appelros et al., 2009). Nevertheless, stroke is usually more severe in women (Appelros et al., 2009) and both genders have distinct morphological and functional features, which often determine the execution of different personal and professional activities. Therefore, we consider that future studies should compare their ULs kinematic metrics.

It is noteworthy that Murphy *et al*. (2012) were the only ones analyzing the influence of age and sex variables in regression models, but no significant influence was found.

Presence of chronic diseases, social and lifestyle factors, psychological, cognitive, and physical factors may impact poststroke recovery trajectories (Kwakkel et al., 2017), as well as affect the reliability of “healthy”/control groups. For example, from the standing position, subjects with distinct BMI are expected to show variability of muscle activations of the trunk, namely in the core stability (AlAbdulwahab & Kachanathu, 2016), and ULs, influencing the performance of these segments (Berrigan, Simoneau, Tremblay, Hue, & Teasdale, 2006). However, few articles included in this review gave importance to anthropometric information. Only in the study of Kim *et al*. (2014), the sitting and table heights were adapted to obtain the same starting position for all participants, whereas other articles (Murphy et al., 2013; Murphy et al., 2012; Wagner et al., 2008) considered the UL’s length to adjust target location. Few articles described also poststroke human adults’ handedness and the articles including right- and left-handed subjects did not analyse the kinematic metrics according to it. Nevertheless, differences in the functional organization of motor areas in right- and left-handed people are known, specifically in sequential movements (Solodkin et al., 2001). Therefore, although the impact of BMI, handedness and other factors is not yet entirely clear, it is recommended that all studies collect this type of information to optimize stratification (Kwakkel et al., 2017).

Concerning the stroke information, no study presented information about initial stroke severity or sub-type, as well as about active hand movement and ability to walk independently at stroke onset. According to SRRR recommendations (Kwakkel et al., 2017), initial stroke severity (through the NIHSS) is one of the core measures to include in all trials, regardless of when the trial starts. Actually, initial stroke severity and age are the strongest predictors of outcome after acute stroke (Kwakkel et al., 2017), which makes them an indispensable information to patients' stratification, and also to obtain valid results and conclusions. Individual item and total NIHSS scores should be reported in future studies (Kwakkel et al., 2017). Active hand movement and walking at admission are recommended particularly in trials that begin later poststroke where NIHSS at stroke onset could not be gathered (Kwakkel et al., 2017).

Another recommended core measure is the FMA (Kwakkel et al., 2017). Most authors used the FMA-UE to measure UL motor impairment and included subjects with *mild* to *severe* motor impairment. Murphy *et al*. (2011) found significant differences between poststroke participants with moderate versus mild UL impairment in the measures of compensatory trunk and UL movements, which is in accordance with other literature (Cirstea & Levin, 2000; Levin, 1996a). van Dokkum *et al*. (2014) also found a significant association between the FMA score and the number of velocity peaks of the "*paretic*" hand. Therefore, future studies should consider the severity level of motor impairment as an important factor for stratification.

Surprisingly, only two articles (Patterson et al., 2011; van Dokkum et al., 2014) indicated the stroke location, whereas the stroke type was reported by several articles (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; van Dokkum et al., 2014). The lesion location is generally assumed to be associated with the specificity of deficits (Nudo, 2013). Furthermore, recent data suggest that the site of ischemic penumbra could predict outcome or treatment response and affect motor recovery (Rosso & Samson, 2014). Therefore, future studies should analyse kinematically the impact of stroke location on UL motor function. To report stroke location and make easier comparisons between studies, the SRRR recommended the following categorization: cortical (internal capsule / middle cerebral artery / frontal lobe), subcortical (thalamus / basal ganglia), midbrain (pons / medulla / cerebellum) and brainstem (Kwakkel et al., 2017).

Curiously, many more articles have gathered information about the "hemiparetic" ("*hemiplegic*", "*affected"* or "*impaired")* side (of the body), rather than the stroke side. Nevertheless, considering the commitment of both ULs after stroke and the recommendations for a bilateral (or global) intervention (Finley et al., 2012; Meskers, Koppe, Konijnenbelt, Veeger, & Janssen, 2005; Nakamura, Abreu, Patterson, Buford, & Ottenbacher, 2008), the terms "*contralesional*" and "*ipsilesional*" should be adopted and the ipsilesional UL should be included in kinematic analysis. Only Finley *et al*. (2012) considered the ipsilesional UL as "*less affected*".

Thrombolysis (Murphy et al., 2013) and imaging to confirm stroke (Wagner et al., 2008) were accounted by one article. Other recent SRRR consensus about biomarkers of stroke recovery (Boyd et al., 2017) highlights the ascendant role that neuroimaging measures need to play in clinical-decision making for poststroke rehabilitation, namely as a measure of molecular/cellular processes that may be difficult to measure directly in humans. Consequently, future studies should collect information about stroke confirmation on imaging and obtainment of computed tomography and magnetic resonance imaging, as recommended (Kwakkel et al., 2017).

Contrariwise, all articles presented the time poststroke onset. Most of the articles analysed poststroke human adults in the chronic phase, however, with an unequal evolution time (from 0.5 up to 14.5 years). Although most poststroke changes occur until the chronic phase (Nudo, 2013), neuromuscular adaptations and modifications of the movement pattern may continue to happen, according to the sensorimotor experiences. Therefore, subjects with distinct evolution times after stroke should not be studied as similar. It is also recommended (Kwakkel et al., 2017) that future studies should also analyse UL movement in the acute phase, since at this time motor deficits result mainly from injury instead of possible compensatory control by alternative neural paths (Lang et al., 2005; Wagner et al., 2006). This knowledge could provide a theoretical framework to create valid and advanced guidelines for the UL neurorehabilitation (Wagner, Lang, Sahrmann, Edwards, & Dromerick, 2007; Wagner et al., 2006), implemented as soon as possible during the acute phase, empowering recovery of the affected function.

4.2 Motor tasks

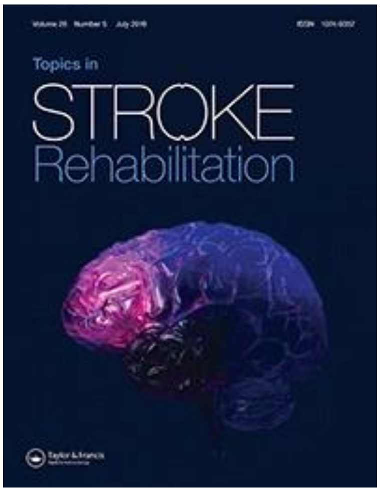
Most articles (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Ozturk et al., 2016; Patterson et al., 2011; van Andel et al., 2008; van Dokkum et al., 2014; Wagner et al., 2008) analysed “functional movements”, being reach and touch a body part, the most accomplished (Aizawa et al., 2010; Chen et al., 2010; van Andel et al., 2008). According to their authors, these movements simulate ADL, related, for example, to personal care and hygiene (Aizawa et al., 2010). In addition, in two articles (Chen et al., 2010; van Andel et al., 2008), “*subjects were asked to copy (van Andel et al., 2008) or to follow (Chen et al., 2010) the movements of the instructor standing in front of them*”, which may affect the execution of participants’ natural movement and the validity of these studies. Since movement varies according to the purpose and constraints of the task (Shumway-Cook & Woollacott, 2017), simulations of ADL or excessive instructions related to movement performance should be avoided. For this reason, we did not consider these simulations real “ADL”. To increase their validity, future studies should focus on real and daily life purpose tasks. Half of the articles included in this review do so, and most of them analysed the drinking task. This seems to be a rich task for kinematic analysis of the UL as it includes sub-tasks such as reaching, grasping, transporting and manipulating an object (Shumway-Cook & Woollacott, 2017), which makes possible the study of these different motor skills. However, it may become too complex for individuals with moderate or severe impairment, which could decrease the amount of participants in these studies. Therefore, simpler ADL are needed to include also subjects with more severe impairment and increase samples. We suggest a task involving just reaching without grasping, e.g. turning on the light.

In summary, the present systematic review identified the collected information and its characteristics about poststroke and healthy/control human adults that are being studied for ULs’ kinematics analysis, and the motor tasks performed in those same studies: age and sex were accounted by almost all articles and some of them also collected medical history; most samples were composed mainly by males, had a low mean age and their anthropometric characteristics were unknown; no study presented information about initial stroke severity or sub-type, as well as about active hand movement and ability to walk independently at stroke onset; most authors used the FMA-UE to measure UL motor impairment and included subjects with different levels of motor impairment; few articles identified handedness of poststroke adults and stroke location, whereas the stroke type was reported by several articles; more articles have gathered information about the “hemiparetic” side, rather than the stroke side; thrombolysis and imaging were accounted by one article; all articles presented the time poststroke onset and most of them analysed poststroke adults in the chronic phase, whose time interval varied greatly; most articles analysed just one UL and “functional movements”, namely ADL simulations. Some gaps were identified in most of the articles reviewed, which may compromise the creation of valid databases of the kinematics of ULs. Therefore, we suggest that future research: (i) analyse the influence of sex and age on the kinematics of ULs; (ii) identify anthropometric characteristics and adjust task environment to them; (iii) report initial stroke severity, location and side and consider these factors to patients’ stratification; (iv) study poststroke human adults in the acute phase; (v) include ipsilesional UL in the analysis; and finally (vi) select real ADL with greater and lesser complexity.

5. Conflict of Interest Statement

The Authors report no conflicts of interest.

<u>Article II</u> - Methodological considerations for kinematic analysis of upper limbs in healthy and poststroke adults Part II: a systematic review of motion capture systems and kinematic metrics



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ABSTRACT

Background and Purpose: To review the methods used to analyse the kinematics of upper limbs (ULs) of healthy and poststroke adults, namely the motion capture systems and kinematic metrics.

Summary of review: A database of articles published in the last decade was compiled using the following search terms combinations: ("upper extremity" OR "upper limb" OR arm) AND (kinematic OR motion OR movement) AND (analysis OR assessment OR measurement). The articles included in this review: (1) had the purpose to analyse objectively three-dimension kinematics of ULs, (2) studied functional movements or activities of daily living involving ULs, and (3) studied healthy and/or poststroke adults. Fourteen articles were included (four studied a healthy sample, three analysed poststroke patients, and seven examined both poststroke and healthy participants).

Conclusion: Most articles used optoelectronic systems with markers; however, the presentation of laboratory and task-specific errors is missing. Markerless systems, used in some studies, seem to be promising alternatives for implementation of kinematic analysis in hospitals and clinics, but the literature proving their validity is scarce. Most articles analysed "joint kinematics" and "end-point kinematics," mainly related with reaching. The different stroke locations of the samples were not considered in their analysis and only three articles described their psychometric properties.

Implication of key findings: Future research should validate portable motion capture systems, document their specific error at the acquisition place and for the studied task, include grasping and manipulation analysis, and describe psychometric properties.

Keywords: Upper extremity, kinematic assessment, stroke, optoelectronic systems, markerless systems, joint kinematics, end-point kinematics.

1. Introduction

More than 80% of stroke patients experience acute sensorimotor dysfunction of the contralesional upper limb (UL), which becomes chronic for more than 40% of the patients (Cramer et al., 1997). Although there seem to be promising approaches to promote ULs recovery after stroke, the quantification of the interventions effectiveness remains limited by the available assessment measures (Thies et al., 2009). Recently, the Stroke Recovery and Rehabilitation Roundtable (SRRR) strongly recommended the inclusion of both core clinical measures and kinematics in poststroke recovery trials (Kwakkel et al., 2017). In clinical setting, UL motor impairment is mainly evaluated by clinical tools such as the Fugl-Meyer Assessment for Upper Extremity (FMA-UE) (Fugl-Meyer et al., 1975) and the Action Research Arm Test (Lyle, 1981), which are based on the examiner's observation (van Dokkum et al., 2014). Though they are both valid instruments (Kwakkel et al., 2017), these clinical measures are strongly influenced by the observer's experience (Patterson et al., 2011). Moreover, since they focus are on task achievement rather than on how tasks are performed (Ozturk et al., 2016), these tools cannot describe the underlying biomechanical characteristics of motor function deficits and, therefore, cannot differentiate restitution (also known as true recovery) from compensation (Kwakkel et al., 2017). Kinematics' parameters are presented as one of the best ways for this purpose and to improve the understanding about the mechanisms that drive motor recovery (Kwakkel et al., 2017).

The kinematic analysis allows an accurate and objective assessment of the ULs motor functions by providing objective and quantitative parameters (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; van Dokkum et al., 2014). However, this requires special equipment (Murphy et al., 2011) and a more complex identification and interpretation of kinematic metrics, which has led to its use mostly in research setting (Murphy et al., 2011).

Accuracy, reliability, high signal-to-noise ratio, compactness and cost are very important features to the kinematic analysis acceptance into routine rehabilitation and to the implementation in clinical setting (Ozturk et al., 2016). Visual marker based optoelectronic systems are often considered the gold standard in the kinematic analysis because of their high accuracy and reliability (Cuesta-Vargas, Galan-Mercant, & Williams, 2010; de los Reyes-Guzmán et al., 2014; Ozturk et al., 2016), and they are used as reference for comparisons with other techniques (Domingues et al., 2016; Vilas-Boas Mdo & Cunha, 2016). These systems use retro-reflective markers (passive or active) which absolute position is detected by multiple video cameras in relation to a reference position (Cuesta-Vargas et al., 2010). However, the difficulty in transportation, required large setup volume, and high cost make them impractical and unaffordable to implement in clinical setting (Ozturk et al., 2016; Thies et al., 2009). Markerless approaches with few cameras, namely Microsoft Kinect, are emerging techniques to study human motion (Di Marco et al., 2017). Nevertheless, it remains unclear exactly what precision these systems can achieve in comparison to the other more established motion analysis systems available on the market (Colyer, Evans, Cosker, & Salo, 2018), namely in kinematic analysis of the poststroke patients ULs. Electromagnetic motion capture systems are another possible alternative due to their small size, high sampling rate and precision (Pérez et al., 2010). They consist of a source that emits an electromagnetic field, which is used to determine the location and orientation of sensors (Cuesta-Vargas et al., 2010). However, the presence of metals (Milne, Chess, Johnson, & King, 1996) and other electromagnetic sources such as cellphones, power lines or other devices, affects these systems and their correction is lengthy and complicated (Cuesta-Vargas et al., 2010). Miniature Inertial Measurement Units (MIMU) are another emerging system (Di Marco et al., 2017) which could be another option, due to their small size and portability (Cuesta-Vargas et al., 2010). They can combine accelerometers, gyroscopes, and magnetometers (Pérez et al., 2010), resulting in increased accuracy (Cuesta-Vargas et al., 2010). Nevertheless, they may undergo electromagnetic interference as well and the degree of accuracy and reliability is site and task specific (Cuesta-Vargas et al., 2010). The variety of available systems triggers the question: what type of system has been used to kinematically assess ULs in healthy and poststroke adults, in the last decade?

In addition, the identification of the most relevant kinematic metrics reflecting ULs motor impairment and functional deficits, as well as their interpretation and translation to clinically interpretable measures, require clarification (Chen et al., 2010; Kwakkel et al., 2017; Murphy et al., 2013; Murphy et al., 2011). Many kinematic metrics have been used in the evaluation of UL movements in poststroke patients (Wagner et al., 2008). Based on the theories of UL movement planning (Shumway-Cook & Woollacott, 2017), these metrics can be classified into two categories: end-point (hand or wrist) kinematic metrics and joint kinematic metrics (de los Reyes-Guzmán et al., 2014; Shumway-Cook & Woollacott, 2017). End-point kinematic metrics are widely calculated by 3D Cartesian coordinates of only one marker on the wrist (or hand) and include linear metrics like peak velocity, movement smoothness and movement straightness of the end-point displacement (de los Reyes-Guzmán et al., 2014). Joint kinematic metrics include joint range of motion and inter-joint correlation (coordination). Trunk displacement has also been used to quantify compensatory strategies and may also be considered within joint kinematics (Ozturk et al., 2016). Subramanian *et al*. (Subramanian, Yamanaka, Chilingaryan, & Levin, 2010) suggested the association between the end-point kinematics and the motor performance, as well as between the joint kinematics and the movement quality. However, this association and its meaning to stroke rehabilitation and research are not well established. Subramanian *et al*. (2010), and other authors (Ozturk et al., 2016), suggested also that movement quality kinematics are more sensitive in identifying UL deficits, while others (Murphy et al., 2011; van Dokkum et al., 2014) have argued that motor performance kinematics are sensitive to change over time and discriminate healthy subjects from those with stroke, as well as subjects with moderate impairment from those with mild impairment. Murphy *et al*. (2013) speculate also that some metrics, like trunk displacement, reflect primarily the component of compensation, and others, like movement smoothness, the restitution. This type of association may be important to evaluate the intervention effect: compensation or restitution.

Based on the presented problems, the aim of this second part was to review and discuss the methods used to analyse the kinematics of ULs of healthy and poststroke adults, namely motion capture systems and kinematic extracted metrics.

2. Methods

The study was conducted using the systematic review method proposed by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis – PRISMA (Moher et al., 2009).

2.1 Research questions

The two main research questions in this study were:

1- What are the motion capture systems used in literature that analysed the kinematics of ULs in healthy and poststroke adults?
2- What are the kinematic metrics extracted in these same articles?

2.2 Search strategy

Two reviewers performed an electronic search on PubMed database and the resource aggregator B-on, namely using the EBSCO EDS interface, to find all the articles published between January 1 2007 and December 31 2017 on the topic of UL kinematic analysis in healthy and poststroke adults. The following search terms combinations were used: (“upper extremity” OR “upper limb” OR arm) AND (kinematic OR motion OR movement) AND (analysis OR assessment OR measurement). The search terms were limited to titles of available full scientific articles, published in academic journals and written in English. The reference lists of all articles were also scanned to identify other potential eligible articles.

2.3 Inclusion and exclusion criteria

The articles included in this review: (i) had the purpose to analyse objectively 3D kinematic of ULs; (ii) studied clearly described functional movements of ULs, or ADL involving ULs (according to van Tuijl *et al.* (2002)); and (iii) studied healthy living adult (>19 years old) humans and/or adult humans with stroke sequelae. The articles excluded from this review: (i) analysed a single UL joint rather than the UL itself, according to the SRRR recommendations (Kwakkel et al., 2017); (ii) studied athletes, to eliminate the sport gesture influence on the UL movement;

(iii) used robots, exoskeletons or virtual realities, to study more realistic contexts; (iv) were meta-analyses, reviews, case reports, pilot studies, technical notes or studies published as conference proceedings.

2.4 Assessment of methodologic quality

The articles included in this systematic review were evaluated using a quality index proposed by Downs and Black (1998). West *et al.* (2002) identified the Downs and Black checklist as being consistent with 18 other recommended quality assessment systems. Studies meeting <60% criteria were considered low quality, ≥60%-<75% moderate quality, and ≥75% high quality. The two searching reviewers independently performed the quality assessment for each of the included articles. Consensus regarding the quality index score for each article was achieved by both authors.

2.5 Data extraction

Data from the included articles were extracted by one reviewer and then checked by a second reviewer using a data extraction table (table 1) which identified: author identification, year of publication, motion capture systems, kinematic metrics and quality index score.

Table 1 – Motion capture systems, kinematic metrics and quality index score.

Authors, Year	*Motion capture systems*	*Kinematic metrics*	*Quality index score (%)*
van Andel *et al.*, 2008	**Optoelectronic system with active LED-markers (Optotrak)** ▪ 3 cameras; ▪ 4 marker clusters of 3 active LED-markers were fixed on the thorax, acromion, upper arm and hand. One marker cluster of 6 active LED-markers was fixed on the forearm.	**Joint kinematics** ▪ <u>Joint angles</u> and <u>ROM</u> of wrist palmar and dorsal flexion, pronation, elbow flexion, humeral internal and external rotation, humeral elevation and scapula lateral rotation.	34%
Wagner *et al.*, 2008	**Optoelectronic system with passive reflective markers (Qualisys)** ▪ 7 cameras; ▪ 16 reflective markers placed on the trunk, upper arm, forearm, hand and fingers.	**End-point kinematics** ▪ <u>Peak hand velocity;</u> ▪ <u>Reach path ratio.</u> Ratio of the actual wrist path traveled to an ideal straight line between the start position and end position; ▪ <u>Trajectory smoothness.</u> Number of peaks in the velocity profile; ▪ <u>Endpoint error.</u> The 3D distance from the third metacarpal marker to the target at end of movement; ▪ <u>Reach extent.</u> The length of the straight line joining the initial and final endpoint positions. **Joint kinematics** ▪ <u>Interjoint coordination</u> of shoulder flexion ROM and elbow extension ROM. ▪ Maximum shoulder flexion and abduction and minimum elbow extension ROM.	63%
Thies *et al.*, 2009	**Inertial system (Xsens)** ▪ An inertial sensor was placed on the forearm.	**End-point kinematics** ▪ <u>Time to complete the tasks.</u>	69%
Aizawa *et al.*, 2010	**Electromagnetic system (O)** ▪ Receivers were fixed on the sternum, upper arm, forearm and hand.	**Joint kinematics** ▪ <u>Joint angles</u> at the completion of the tasks for shoulder (thoracohumeral joint) elevation, shoulder plane of elevation shoulder axial rotation, elbow flexion, forearm rotation, wrist flexion and wrist deviation.	56%

(continued)

Table 1. (Continued).

Authors, Year	Motion capture systems	Kinematic metrics	Quality index score (%)
Chen *et al.*, 2010	**Optoelectronic system with passive reflective markers (Vicon)** ▪ 14 reflective markers placed on thorax, clavicle, scapula, humerus and forearm.	▪ Dexterity measure; ▪ Manipulability ellipsoid.	50%
Murphy *et al.*, 2011	**Optoelectronic system with passive reflective markers (Qualisys)** ▪ 5 cameras; ▪ 7 reflective markers placed on hand, wrist, elbow, right and left shoulders, thorax and face.	**End-point kinematics** ▪ Absolute and relative movement times for each phase and the entire movement; ▪ Peak tangential velocity of the hand and time and percentage of time to peak hand velocity (during reaching phase); ▪ First velocity peak and the time and the percentage of time to first peak (during reaching phase); ▪ Number of movement units. Movement unit was defined as a difference between a local minimum and next maximum velocity value that exceeded the amplitude limit of 20 mm/s on the hand marker velocity profile; the time between 2 subsequent peaks had to be at least 150 ms (during reaching and forward transport phases). **Joint kinematics** ▪ Peak angular velocity of the elbow joint (during reaching phase); ▪ Angular joint motions for elbow flexion/extension, shoulder flexion/extension and shoulder abduction/aduction; ▪ Joint angles for maximal elbow extension and shoulder flexion during reaching as well for maximal shoulder abduction and flexion (during drinking); ▪ Trunk displacement. Maximal displacement of the thorax marker from the initial position (during entire drinking task); ▪ Interjoint coordination between the shoulder and elbow joint angles (during reaching phase).	72%
Patterson *et al.*, 2011	**Optoelectronic system with passive reflective markers (Vicon)** ▪ 12 cameras; ▪ Reflective markers placed on trunk, pelvis, arms, wrist, hand and fingers.	**End-point kinematics** ▪ Movement time; ▪ Peak velocity; ▪ Index of curvature (ratio of the path length and the line-of-sight distance between the initial to the final endpoint position). **Joint kinematics** ▪ Trunk displacement. ▪ Maximum aperture. Maximum displacement between the thumb and index finger. ▪ Percentage of movement cycle where maximum aperture occurs. The time point in the reach cycle that maximum aperture occurred.	59%

(continued)

Table 1. (Continued).

Authors, Year	*Motion capture systems*	*Kinematic metrics*	*Quality index score (%)*
Finley *et al.*, 2012	**Electromagnetic system (Motion Monitor)** ▪ "Mini-bird" sensors were placed on the acromion, distal to sternal notch of the manubrium, superior to the epicondyle of the arm, the distal radius and the posterior third metacarpal.	**Joint kinematics** ▪ Joint angles of shoulder flexion and elbow extension. **End-point kinematics** ▪ Mean velocity; ▪ Peak velocity; ▪ Mean/peak velocity (smoothness metric); ▪ Movement duration.	75%
Murphy *et al.*, 2012	**Optoelectronic system with passive reflective markers (Qualisys)** ▪ 5 cameras; ▪ 7 reflective markers placed on hand, wrist, elbow, right and left shoulder, thorax and face.	**End-point kinematics** ▪ Total movement time; ▪ Number of movement units. **Joint kinematics** ▪ Peak angular velocity of the elbow joint; ▪ Trunk displacement. Maximal displacement of the thorax marker in sagittal plane from the initial position.	72%
Murphy *et al.*, 2013	**Optoelectronic system with passive reflective markers (Qualisys)** ▪ 5 cameras; ▪ 7 reflective markers placed on hand, wrist, elbow, right and left shoulder, thorax and face.	**End-point kinematics** ▪ Total movement time; ▪ Number of movement units. **Joint kinematics** ▪ Trunk displacement. Maximal displacement of the thorax marker in sagittal plane from the initial position.	78%
van Dokkum *et. al*, 2014	**Electromagnetic system (FASTRAK Polhemus)** ▪ Sensors were placed along the main axis of both hands, at the head of the third metacarpal.	**End-point kinematics** ▪ Movement time; ▪ Peak hand velocity; ▪ Time of maximum velocity; ▪ Trajectory length; ▪ Trajectory directness (the curvature index); ▪ Number of velocity peaks; ▪ Movement irregularity. It is measured by the ration between peak and mean speed.	59%

(continued)

Table 1. (Continued)

Authors, Year	Motion capture systems	Kinematic metrics	Quality index score (%)
Kim *et al.*, 2014	**Optoelectronic system with passive reflective markers (Vicon)** ▪ 9 cameras; ▪ 13 reflective markers placed on trunk, arm, forearm and hand.	**End-point kinematics** ▪ Movement time of complete task and each phase; ▪ Phase ratio. Portion of each phase expressed in %. **Joint kinematics** ▪ Joint angles (maximum and minimum angles), ROM and range of difference angle (between stroke and healthy participants) in each phase of the task of shoulder extension-flexion, shoulder adduction-abduction, shoulder internal-external rotation, elbow flexion-extension, elbow pronation-supination, ulnar-radial deviation and wrist flexion-extension; ▪ Angular velocities of the flexion and extension motions of the shoulder and elbow joints, in each phase of the task.	50%
Ozturk *et al.*, 2016	**Optoelectronic system (Microsoft Kinect v2)** ▪ Depth sensor; ▪ A color camera; ▪ Four-microphone array.	**End-point kinematics** ▪ Spectral arc-length. Based on the Fourier magnitude spectrum was used to quantify smoothness of the wrist (hand); ▪ Maximum speed of the wrist (hand); ▪ Index of Curvature. **Joint kinematics** ▪ Trunk displacement; ▪ Inter-joint coordination index between shoulder flexion/extension and elbow flexion/extension.	38%
Jacquier-Bret *et al.*, 2017	**Optoelectronic system with passive reflective markers (Qualisys)** ▪ 6 cameras; ▪ 22 reflective markers placed on the head, trunk and right UL.	**Joint kinematics** ▪ ROM and joint angles of shoulder flexion/extension, shoulder abduction/adduction, elbow flexion/extension and wrist flexion/extension; - Relation between wrist flexion/extension and elbow flexion/extension; - The slope of the linear equation of the major axis. These slopes were plotted in a normalized quadrant divided into three equal sector (each portion covers a sector of 30°) represented by black lines. A straight that belongs to the upper area (light grey) corresponds to a higher solicitation of the wrist. On the contrary, a straight that belongs to the lower area (dark grey) is interpreted as a higher solicitation of the elbow joint. The central area (white area) represents an equal solicitation of the two joints. **End-point kinematics** ▪ ROM and the lengths of the paths of the wrist; ▪ Movement time.	53%

Abbreviation: ROM – Range of motion; UL – Upper Limb.

3. Results

3.1 Search yield

The search strategy revealed 471 results and 3 other articles were identified through the reference lists (table 2). After an initial examination, 329 were rejected as copies of the same article; the remaining 145 articles were then reviewed by the two independent reviewers. From these, 86 were not included since they: (i) studied sport gestures, passive movements, purposeless or unclear movements; (ii) and/or examined children, animals, corpses or other pathologic conditions. From the 59 included articles, 45 were excluded as they: (i) analysed only one joint of the UL; (ii) were in athletes; (iii) used robots, exoskeletons or virtual realities; (iv) and/or were meta-analyses, reviews, case reports, pilot studies, technical notes or studies published as conference proceedings.

A total of 14 articles were considered in the current review as shown in Figure 1, of which four included a healthy sample (Aizawa et al., 2010; Chen et al., 2010; Jacquier-Bret et al., 2017; van Andel et al., 2008), three studied poststroke patients (Murphy et al., 2013; Murphy et al., 2012; Wagner et al., 2008) and seven comprised both a stroke group and a healthy/control group (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014).

Table 2- Number of articles collected from PubMed and B-on.

Search terms	*PubMed*	*B-on*	*References*
"upper extremity" OR "upper limb" OR arm AND kinematics OR motion OR movement AND analysis OR assessment OR measurement	20	451	3

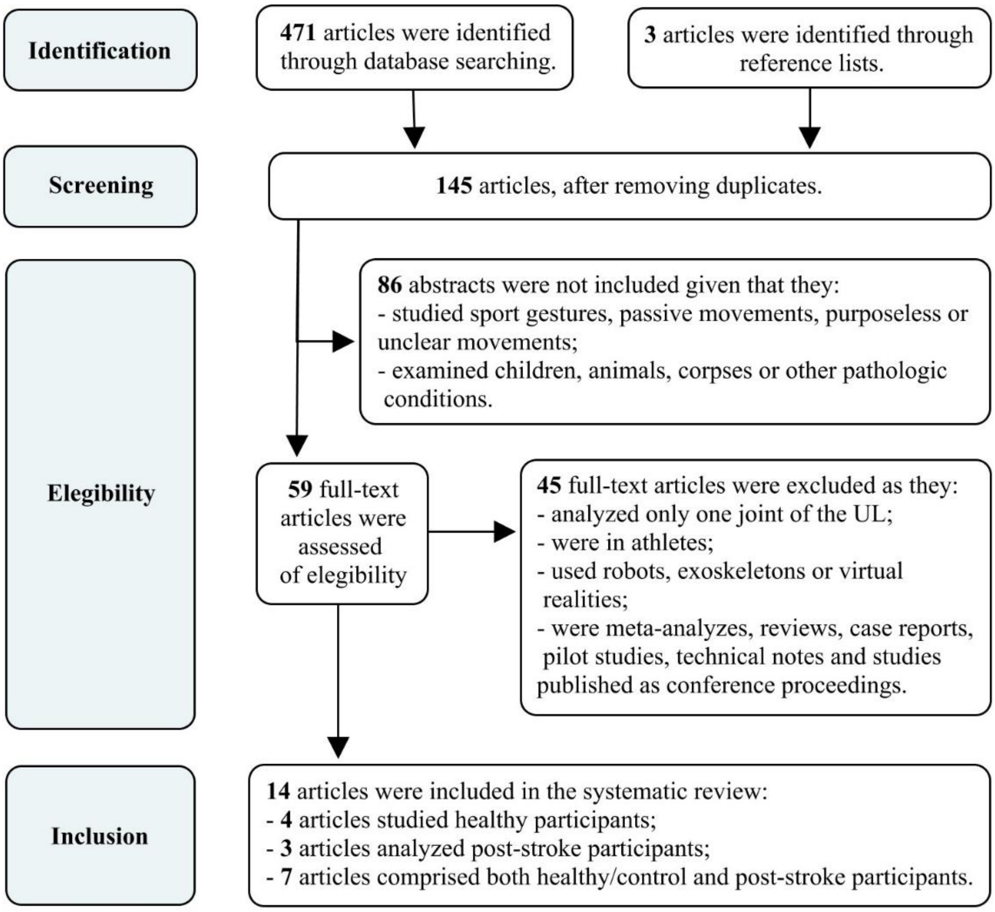

Figure 1. Review selection and exclusion criteria.

3.2 Motion capture systems

The most widely used type of motion capture system, either in articles with healthy participants or in articles with poststroke participants, was the optoelectronic with passive markers (Chen et al., 2010; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; Wagner et al., 2008), with a number of cameras ranging from five (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011) to twelve (Patterson et al., 2011). Chen *et al*. (2010) were the only ones who did not identified the number of cameras used. Other two articles used other opto-eletronic systems variations: one selected active LED-markers with three cameras (van Andel et al., 2008) and the other chose the Microsoft Kinect v2 with one camera (Ozturk et al., 2016).

Other three articles (Aizawa et al., 2010; Finley et al., 2012; van Dokkum et al., 2014) used electromagnetic systems and only one article (Thies et al., 2009) used an inertial system.

3.3 Kinematic metrics

Most articles analysed both “joint kinematics” and “end-point kinematics” (Finley et al., 2012; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; Wagner et al., 2008); two (Thies et al., 2009; van Dokkum et al., 2014), involving poststroke adults, analysed only “end-point kinematics”; and two (Aizawa et al., 2010; van Andel et al., 2008), involving just healthy adults, analysed only “joint kinematics”. Chen *et al*. (2010) analysed two variables related to robotic applications, which do not fit the above categorization: “dexterity measure” and “manipulability ellipsoid”.

In descending order of use frequency, the analysed “end-point kinematics” were: movement duration (Finley et al., 2012; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014); peak velocity (Finley et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008); number of movement units (or velocity peaks) (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008); index of curvature (or reach path ratio) (Ozturk et al., 2016; Patterson et al., 2011; van Dokkum et al., 2014; Wagner et al., 2008); reach extent (or trajectory length) (Jacquier-Bret et al., 2017; van Dokkum et al., 2014; Wagner et al., 2008); absolute and relative times for each phase (Kim et al., 2014; Murphy et al., 2011); time and percentage of time to peak velocity (Murphy et al., 2011; van Dokkum et al., 2014); mean/peak velocity (Finley et al., 2012; van Dokkum et al., 2014); end-point error (Wagner et al., 2008); first velocity peak, time and percentage of time to first peak (Murphy et al., 2011); and mean velocity (Finley et al., 2012).

In descending order of use frequency, the analysed “joint kinematics” were: joint angles of shoulder and elbow (Aizawa et al., 2010; Finley et al., 2012;

Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2011; van Andel et al., 2008); trunk displacement (Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011); joint angles of wrist (Aizawa et al., 2010; Jacquier-Bret et al., 2017; Kim et al., 2014; van Andel et al., 2008); range of motion of shoulder, elbow (Jacquier-Bret et al., 2017; Kim et al., 2014; van Andel et al., 2008; Wagner et al., 2008) and wrist (Jacquier-Bret et al., 2017; Kim et al., 2014; van Andel et al., 2008); interjoint coordination between shoulder and elbow (Murphy et al., 2011; Ozturk et al., 2016; Wagner et al., 2008); peak angular velocity of elbow (Murphy et al., 2012; Murphy et al., 2011); angular joint motion for shoulder and elbow (Murphy et al., 2011); angular velocities of shoulder and elbow (Kim et al., 2014); maximum aperture and percentage of movement cycle where maximum aperture occurs (Patterson et al., 2011).

4. Discussion

In this second part of systematic review, we analysed the same literature of the first one (Mesquita, Pinheiro, et al., 2019) in order to identify which were (1) the motion capture systems that were being used in healthy and poststroke adults, and (2) the kinematic metrics extracted in these same articles. In addition, this systematic review triggers a reflection on relevant elements to be considered in future studies.

4.1 Motion capture systems

First, most of the articles used optoelectronic systems (with passive markers), possibly because this type of system is more widespread, is accurate and presents the best relation between the advantages and the limitations regarding its use, when comparing with other systems (Colyer et al., 2018; Vilas-Boas Mdo & Cunha, 2016). However, the laboratory and task specific error assessments to guarantee the control of whole measurement process (Eichelberger et al., 2016) is missing in most of the reviewed studies, which can compromise their validity and comparison between them. Actually, the data of optoelectronic systems could suffer from a number of inaccuracy sources, collectively termed instrumental errors (Di Marco et al., 2017), due to the use of a camera-based approach which has been found to be dependent on: the number and position of the cameras (Marco, Rossi, Patanè, & Cappa, 2015; Windolf, Gotzen, & Morlock, 2008), their lens distortion (Weng, Cohen, & Herniou, 1992), the dimension of the capture volume (Vander Linden, Carlson, & Hubbard, 1992), and the algorithms used for the reconstruction of a marker's 3D position (Abdel-Aziz, Karara, & Hauck, 2015). The number of cameras was the only referred factor to be mentioned by most authors, with the exception of the study of Chen *et al.* (2010). Position of the cameras was only referred in the study of Murphy *et al*. (2011). Eichelberger *et al*. (2016) advocated that instrumental errors should also be determined and documented relative to various task-specific movement protocols to guarantee a high-quality research. Therefore, according to these recommendations (Eichelberger et al., 2016; Vander Linden et al., 1992; Windolf et al., 2008), future research should evaluate the system-specific error in the laboratory and for the task performed, presenting that data.

Because of the difficulty in transportation, required large setup volume and high cost, optoelectronic systems hampers evaluation of poststroke patients in acute and sub-acute phases, during hospitalization or at rehabilitation centers (Ozturk et al., 2016; Thies et al., 2009). In fact, only two articles (of Murphy *et al*.) involving this type of systems, evaluated subjects in the acute phase (Murphy et al., 2013) and sub-acute (Murphy et al., 2012) phases after stroke, respectively (please see the first part of the review (Mesquita, Pinheiro, et al., 2019) for more details regarding sample characteristics). Other two articles analysed poststroke adults in the acute and sub-acute phases using an electromagnetic system (van Dokkum et al., 2014) and the Microsoft Kinect (Ozturk et al., 2016), respectively. Just one study (Thies et al., 2009), which analysed the chronic phase, used an inertial system. Although these portable systems appear to be promising alternatives for the kinematic analysis of the ULs in stroke patients, the literature proving its validity for this purpose is scarce (Cuesta-Vargas et al., 2010; Milne et al., 1996; Webster & Celik, 2014) and it is likely to benefit from reproducibility of outcome measures.

Therefore, in the coming years, it is emergent to focus on the development of accurate and reliable motion acquisition systems which do not encumber the performer or influence their natural movement and that can be easily transported and used in a hospital or other clinical context. These systems will allow the evaluation of more subjects in the different stages of poststroke rehabilitation and, consequently, they will contribute to a deeper understanding of the mechanisms underlying the motor recovery of the ULs after stroke.

4.2 Kinematic metrics

The authors of the articles under review analysed several different linear and angular kinematic variables which may be related to the lack of clarity regarding the ULs motor planning (Shumway-Cook & Woollacott, 2017), i.e.: are ULs movements planned by joint angle and/or by end-point coordinates? Most authors analysed “joint kinematics” and “end-point kinematics”, of which “movement time”, “peak velocity”, “number of movement units (velocity peaks)”, “joint angles of shoulder and elbow” and “trunk displacement” were the most studied. According to Reyes-Guzmán *et al*. (2014), these kinematic metrics quantify different characteristics of the UL movements: “movement time” and “peak velocity” are related with the speed; the “number of velocity peaks” measure the smoothness; the “joint angles of shoulder and elbow” translate the functional range of motion; and the “trunk displacement” show compensation. Despite this, we should question if their analysis is sufficient to improve the understanding about the mechanisms driving motor recovery and to differentiate restitution from compensation. Furthermore, UL function includes reaching, grasping, moving and manipulating objects in a great number of activities of daily living(Shumway-Cook & Woollacott, 2017). The above mentioned measurements are mainly associated with reaching, but they do not measure the abilities to open the hand, to grasp, to hold and to move objects. Although many authors have defined as an inclusion criterion the ability to perform tasks involving these skills, such as drinking, they did not evaluate them in their studies. Patterson *et al*. (2011) were the only ones who analysed index finger and thumb movements, namely maximum aperture and percentage of movement cycle where maximum aperture occurs. Without linear and angular data characterizing the ability to open and close the hand the clinical utility of the current data appears to be very limited. Further studies should examine grasping and manipulation to ensure appropriate assessment, intervention and patients’ integration into the daily life.

In addition to the lack of clarity regarding the ULs motor planning, the variability in stroke extension and location (Mesquita, Pinheiro, et al., 2019) increases the difficulty in the definition of the variables set to analyse. Depending on the injured area, the deficits may result from problems in target location, eye-hand coordination, temporal coordination, postural control, motor units recruitment, among others (Shumway-Cook & Woollacott, 2017). Therefore, should kinematic variables set be defined without considering the stroke location and respective affected functions? Stroke describes a very heterogeneous group of clinical conditions that are unified by a vascular injury, but not by size, location, or impact of injury (Boyd et al., 2017). Despite this, clinical trials are often designed with a "one size fits all" point of view (Boyd et al., 2017). The articles included in this review analysed the variables without considering the different stroke locations and studied the participants as a homogeneous sample, which can make them vulnerable to patient heterogeneity. Thus, to improve specific and effective neurorehabilitation strategies, it is crucial that future studies direct their attention to the influence of the stroke location on ULs' movement to allow a better understanding of the produced deficits. If the establishment of homogeneous groups regarding stroke location is not conceivable, case series and/or case-control series should be considered as more appropriate studies to understand this question.

One last important issue is the paucity of information describing the psychometric properties (e.g., reliability, validity, and sensitivity to change) of kinematic metrics of UL (Barak & Duncan, 2006; Roby-Brami et al., 2003). Only three articles (Murphy et al., 2013; Patterson et al., 2011; Wagner et al., 2008) described psychometric properties of kinematic assessment, namely the reliability (Patterson et al., 2011; Wagner et al., 2008) and the responsiveness to external change (Murphy et al., 2013). To establish a core set of kinematic outcomes, it is important that future studies describe their psychometric properties, either when they use kinematic variables as discriminative measures (to discriminate UL motor performance of people with stroke from that of people without stroke), or when they use them as evaluative measures (to evaluate longitudinal change in UL motor performance) (Wagner et al., 2008). For use as a discriminative measure, kinematic data must demonstrate construct validity and reliability based on stable between-subject variations (Wagner et al., 2008). For use as an evaluative measure, kinematic data must demonstrate longitudinal construct validity, reliability based on stable within-subject variations, and responsiveness (the ability to detect minimal clinically important change) (Wagner et al., 2008).

In summary, the present systematic review identified the motion capture systems used and kinematic metrics extracted for ULs' kinematic analysis: most articles used optoelectronic systems, however, without presentation of laboratory-or task-specific errors; and most authors analysed "joint kinematics" and "end-point kinematics", mainly related with reaching. Markerless systems, used in some studies, seem to be promising alternatives for implementation of kinematic analysis in hospitals and clinics, but the literature proving their validity is scarce. The different stroke locations of participants were not considered in the analysis of kinematic metrics and only three articles described their psychometric properties. Therefore, some gaps were identified in most of the articles analysed, which may compromise the creation of valid databases of ULs kinematics. To avoid these problems, future research should: (i) validate the emergent portable motion capture systems to kinematic assessment of ULs; (ii) document the specific error of the motion capture systems at the acquisition place and for the studied task; (iii) include grasping and manipulation analysis; (iii) study the influence of the stroke location on ULs kinematic metrics; (iv) and describe their psychometric properties.

5. Conclusion

The Authors report no conflicts of interest.

6. Funding

There is no funding.

Article III - A comprehensive kinematic characterization of the drinking task performed by healthy adults

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Journal: (submitted)

ABSTRACT

Introduction: Recently, the inclusion of upper limb (UL) kinematic analysis in poststroke recovery trials were recommended to improve the understanding about motor recovery. Since the preexisting studies present shortcomings in sampling, experimental setup and kinematic metrics, knowledge of normative values of healthy adults is lacking and necessary. Therefore, this study aimed to describe the ULs kinematic of healthy adults during an activity of daily living (ADL) – drinking - and to analyse if age, sex, dominance and body mass index (BMI) exerted any effect on the strategies used. Methods: 63 adults, aged 30 to 69 years old, drank water, using both ULs, separately. Experimental setup was set considering the anthropometric characteristics of each participant. Movement was captured by a 3D motion capture system. Drinking task was divided into five phases (reaching, forward transporting, drinking, backward transporting and returning), detailed by end-point and joint kinematics. A multifactorial analysis of variance was applied on the kinematic metrics, using age, sex, BMI and dominance as main factors. Results: Backward transporting was the longest phase (2.547 ± 0.444 s; 32.2 ± 3.0 %) and the returning was the fastest one (0.354 ± 0.070 m/s). Peak velocity occurred earlier in reaching (32.5 ± 5.3 %) and forward transporting (36.4 ± 4.8 %) phases and later in backward transporting (51.3 ± 5.6 %) and returning (52.2 ± 10.4 %) phases. Forward transporting was the most efficient (1.019 ± 0.009) and smoothest phase (1.0 ± 0.0). Maximum magnitude of the hand aperture was slightly higher (0.119 ± 0.009 m) and late in reaching (67.6 ± 7.6 %). Greater ranges of motion were observed in the sagittal plane of the shoulder and elbow and in the frontal plane of the wrist. Trunk also moved mainly in the sagittal plane. Age and sex were the main factors exerting effect on some of the kinematics related to speed, hand aperture, joint angles and compensation. Conclusion: Drinking task has five phases with different motor skills and kinematic strategies that were mainly influenced by age and sex. It is necessary to study other ADL with less difficulty, to ensure maximum understanding of the UL motor control and to allow the study of UL motor performance of poststroke adults with hand impairment.

Key words: upper limb; motor control; motor performance assessment; kinematic analysis; activities of daily living

1. Introduction

Kinematic analysis has become an increasingly important tool in the evaluation of subjects with movement system dysfunction, particularly in poststroke adults. Recently, the Stroke Recovery and Rehabilitation Roundtable (SRRR) recommended the inclusion of kinematic analysis in poststroke recovery trials and the establishment of a core set of kinematic outcomes to improve the understanding about the mechanisms that drive motor recovery (Kwakkel et al., 2017). This type of analysis allows to describe the underlying biomechanical characteristics of motor function, enabling the differentiation of restitution from compensation mechanisms, which becomes increasingly important for an optimized rehabilitation (Kwakkel et al., 2017). The understanding of these mechanisms presumes, therefore, the knowledge of typical movement (performed by healthy adults). Although in the last decade some studies (Aizawa et al., 2010; Chen et al., 2010; Jacquier-Bret et al., 2017) were dedicated to the kinematic analysis of the ULs in healthy population, there is a current little in-depth knowledge about the UL typical movement kinematics, which may be the missing piece to optimize the UL recovery.

Selecting an activity of daily living (ADL), in other words a goal-oriented task, for kinematic analysis allows to increase the study's validity and it is defended by several authors (de los Reyes-Guzmán et al., 2014; Kim et al., 2014; Mesquita, Pinheiro, et al., 2019; Murphy et al., 2012; Murphy et al., 2011). Drinking has been one of the most selected ADL to analyse the UL function (Mesquita, Pinheiro, et al., 2019), particularly in studies involving poststroke adults (Aprile et al., 2014; Kim et al., 2014; Murphy et al., 2018; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009). The choice of this particular ADL may result from the possibility of analyzing different motor skills of UL, like reaching, grasping, and transporting an object (Murphy et al., 2006).

Although the choice of drinking task seems to be adequate for kinematic analysis of the UL, some of the preexisting studies present shortcomings in the sampling (Mesquita, Pinheiro, et al., 2019), the experimental setup and in the analysed kinematic metrics (Mesquita, Fonseca, Pinheiro, et al., 2019), which can compromise their validity and use of data for creating reliable databases. Evidence shows that age (Fradet et al., 2008; Morgan et al., 1994; Pohl et al., 1996; Vrtunski & Patterson, 1985; Welford, 1982; Williams, 1990), body mass index (BMI) (AlAbdulwahab & Kachanathu, 2016) and handedness (Solodkin et al., 2001) are responsible for differences in postural control, mobility skills and in the functional organization of motor areas. Furthermore, it is also known that UL motor strategies vary according to task environment and constraints (Shumway-Cook & Woollacott, 2017). However, in some of these studies, the recruited healthy control participants were much younger than those belonging to the poststroke groups (Aizawa et al., 2010; Kim et al., 2014), the possible influence of their sex (Aprile et al., 2014; Kim et al., 2014; Murphy et al., 2006; Murphy et al., 2011) and handedness (Aprile et al., 2014; Kim et al., 2014; Murphy et al., 2006) was omitted, the anthropometric characteristics were unknown (Maitra & Junkins, 2004; Murphy et al., 2011; Thies et al., 2009) and the experimental setup was not adapted to each participant (Aprile et al., 2014; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011). In addition, certain authors (Thies et al., 2009) only analysed the "end-point kinematics", while others (Aizawa et al., 2010) focused solely in the "joint-kinematics". Based on the theories of UL movement planning (Shumway-Cook & Woollacott, 2017), kinematic metrics can be classified into these two categories(de los Reyes-Guzmán et al., 2014; Shumway-Cook & Woollacott, 2017). End-point kinematic metrics are widely calculated by 3D Cartesian coordinates of hand and include several linear metrics which can characterize for example speed, efficiency, smoothness and control strategy of movement (de los Reyes-Guzmán et al., 2014). Joint kinematic metrics include joint range of motion, which can characterize functional range of motion, among others less studied variables. The decision to analyse only one of these types of kinematic metrics may have excluded important data, since it is not clear whether the central nervous system (CNS) programs movements exclusively by end point coordinates or by joint angle coordinates (Shumway-Cook & Woollacott, 2017). The authors who analysed the two sets of kinematic metrics selected only one or two metrics of these sets (Murphy et al., 2013; Murphy et al., 2012) and focused their analysis essentially on the reaching phase (Murphy et al., 2018; Murphy et al., 2011), without analysing the pre-shaping that precedes the glass grasping. Therefore, authors seem to be missing the analysis of skills, such as grasping and transporting, present in so many ADLs.

The study of these overlooked factors and the inclusion of end-point and joint kinematics in the analysis could point to new understandings regarding the motor strategies used to drink and, consequently, support the understanding about motor recovery after stroke. In this sense, the goal of this study was to analyse the kinematic of the ULs of healthy adults during the performance of the drinking task through the analysis of end-point and joint kinematics in all its phases (reaching, forward transporting, drinking, backward transporting and returning). Moreover, we aimed to understand if age, sex, dominance and BMI influence the kinematic strategies used.

2. Methods

2.1. Study design and participants

A cross-sectional observational study was carried out in a laboratory setting, after approval by the Ethics Committee of Faculty of Sports of University of Porto (process CEFADE 08.2016). Though by responding to the online questionnaire subjects' consent was automatically considered, an additional written informed consent was obtained from all participants, according to the Helsinki Declaration.

Sample was recruited from a population of students, teaching and non-teaching staff from higher education institutions, contacted through e-mail; on this e-mail, people were informed about the study and invited to participate by fulfilling a characterization and inclusion/exclusion criteria selection questionnaire. From the two hundred and seventeen subjects that answered the questionnaire, sixty-three fit the criteria and were recruited. Subjects were included if they were ≥30 years old, had a body mass index (BMI) between 18.5 and 30.0, were right-handed (Murphy et al., 2006; Murphy et al., 2011), and had an insufficient physical activity level, i.e. not achieving 150 minutes of moderate-to-vigorous-intensity physical activity per week or 75 minutes of vigorous-intensity physical activity per week or an equivalent combination of moderate- and vigorous-intensity activity (Tremblay et al., 2017). The existence of musculoskeletal or neurological conditions which might affected the UL function, previous history of UL pathology or surgery and pain in this segment, and pregnancy were considered exclusion criteria. Table 1 presents the sample's demographic and anthropometric characteristics.

Table 1 - Demographic and anthropometric characteristics of the sample.

Characteristics, n=63	*Mean ± SD (Min-Max) or n (%)*
Age (years)*	46.8 ± 11.7 (30.0-69.0)
Age category‡	45 (71%) 30-55 years old, 18 (29%) 56-74 years old
Sex‡	25 (40%) Male, 38 (60%) Female
Height (m)*	1.63 ± 0.11 (1.37-1.84)
Weight (kg)*	66.88 ± 11.28 (49.00-100.00)
Length of the right upper limb (cm)*	56.63 ± 3.87 (48.50-66.50)
Length of the left upper limb (cm)*	56.61 ± 3.91 (48.50-66.50)
Body Mass Index*	25.05 ± 2.72 (19.70-29.90)
Body Mass Index Category ‡	29 (46%) Normal, 34 (54%) Overweight

*Mean, standard deviation, minimum and maximum values for continuous variables; ‡ n (%) for categorical variables

2.2. Motion capture system and marker setup

Drinking movements were captured using eleven Oqus Qualisys cameras (Qualisys AB, Gotenburg, Sweden) operating at a sampling frequency of 200 Hz. Prior to each session the camera system was calibrated with a measurement volume of approximately 8 m^3 and a maximum acceptable error of 0.8 mm. A twenty-five reflective marker setup was used to create an upper body biomechanical model comprising both ULs, trunk and pelvis (figure 1). Pelvis was modeled through four markers over the right and left posterior and anterior iliac spines (RPSIS, LPSIS, RASIS and LASIS); trunk was modeled by five markers on the right and left acromion (RAC and LAC), the 7th cervical vertebra (C7), over the incisura jugularis (IJ) and the xyphoid process (PX); and ULs were modeled by seven markers over the ipsilateral acromion (RAC/LAC), the lateral and medial epicondyles of the humerus (RLELB/LLELB and RMELB/LMELB), the styloid processes of radius and ulna (RRAD/LRAD and RULN/LULN), on the lateral side of the head of the second metacarpal (RLH/LLH), and on the medial side of the head of the fifth metacarpal (RMH/LMH). Additional markers were placed on the posterior side of the distal phalange of thumb and index (RTHUMB/LTHUMB and RINDEX/LINDEX) to analyse hand aperture.

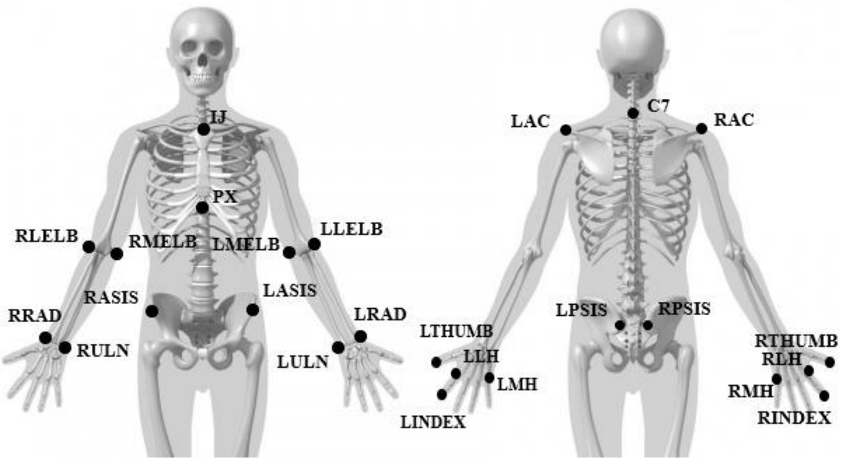


Figure 1: Anatomical marker set used to model the pelvis, trunk and upper limbs.

Abbreviation: C7 - processus spinous of the 7th cervical vertebra; IJ – incisura jugularis; LAC – middle part of left acromion; LASIS – left anterior superior iliac spine; LINDEX- distal phalange of left índex; LLELB –lateral epicondyle of left humerus; LLH – lateral side of the head of the second left metacarpal; LMELB – medial epicondyle of left humerus; LMH - medial side of the head of the fifth left metacarpal; LPSIS – left posterior superior iliac spine; LRAD –styloid process of left radius; LTHUMB – distal phalange of left thumb; LULN – styloid process of left ulna; PX- processus xiphoideus; RAC –middle part of right acromion; RASIS – right anterior superior iliac spine; RINDEX- distal phalange of right índex; RLELB –lateral epicondyle of right humerus; RLH –lateral side of the head of the second right metacarpal; RMELB – medial epicondyle of right humerus; RMH- medial side of the head of the fifth right metacarpal; RPSIS – right posterior superior iliac spine; RRAD – styloid process of right radius; RTHUMB – distal phalange of right thumb; RULN –styloid process of right ulna.

2.3. Experimental setup and procedures

Drinking was performed in a seated position on a hydraulic gurney, whose height was adjusted to 100% of the leg length of each subject (figure 2) (Michaelsen, Luta, Roby-Brami, & Levin, 2001). The base of support and the location of the table and the glass were also normalized according to the anthropometric characteristics of each subject; all subjects sat with three-fourths of the femur length supported (Michaelsen et al., 2001), the feet parallel to the hips width, with hands resting on the respective ipsilateral thigh with the palm downward. The drinking glass was placed on a table, whose height was adjusted to the olecranon’s height (Kim et al., 2014), in the sagittal plane of the ipsilateral hip, at a distance of this joint equal to the length between the acromion and the trapezius-metacarpal joint of ipsilateral UL. To ensure that the participants placed the glass in the same place from where they lifted it, a small round base was placed on the location determined for the glass. The drinking glass had 7.0 cm in diameter and 9.5 cm of height (volume 240 mL) and was filled with 120 mL of water (half-full) (Murphy et al., 2006; Murphy et al., 2011).

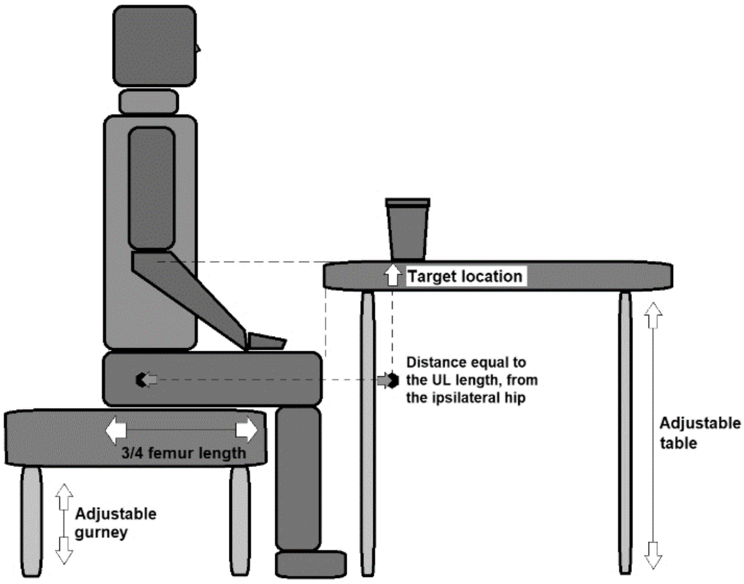


Figure 2. Experimental setup of drinking task (of right UL).

Abbreviation: UL – upper limb

Participants practiced the task a few times before registering. Prior to data collection, a static file was registered for later construction of the anatomical model in Visual3D software (C-Motion, Inc., Germantown, USA). Then, participants were instructed to, when hearing the command “you can drink”, to take a sip of water at a comfortable self-paced speed (Aizawa et al., 2010; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009) starting randomly with right or left UL. After the task, participants were instructed to remain stable for 3 seconds (Aizawa et al., 2010), while looking steadily at the target. Three trials with the same volume of water were performed for each UL, with a break of one minute before each trial.

2.4. Data processing and analysis

After the recording phase, the Qualisys Track Manager software (Qualisys AB, Gotenburg, Sweden) was used to identify each marker trajectory and to review if it was tracked correctly throughout the data capture. Trajectory gaps were interpolated using the built-in polynomial calculations, and the resulting data was exported to the Visual3D software (C-Motion, Inc., Germantown, USA) for further analysis. This software was used to build a biomechanical upper body model using individual anthropometric measurements and markers (according to appropriate C-motion recommendations (C-Motion, 2017)), to filter the movement trajectory data with a 6 Hz low-pass Butterworth filter, and to perform all the events detections and metric calculations. A global and local coordinate system (for each segment) has been defined in which the X axis corresponded to the lateral (+) and medial (-) directions, the Y axis corresponds to the anterior (+) and posterior (-) directions, and the Z axis corresponds to the cephalic (+) and caudal (-) directions (Kim et al., 2014). Joint angles were calculated using the rotation order of the distal segment with respect to the proximal segment, applying each segment's local coordinate system (Kim et al., 2014).

The drinking task was, according to the literature (Kim et al., 2014; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011), divided into five phases (figure 3): (a) reaching out for the glass from starting position, (b) transporting the glass forward to the mouth, (c) taking a drink (one sip), (d) transporting the glass backward to the pickup point, and (e) returning the hand to the initial position. Movement onset was defined as the time when the tangential velocity of the hand exceeded 2% of the maximum velocity in the reaching phase (Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011). Start of forward transport phase was defined as the time when the tangential velocity of the hand exceeded 0.15 m/s after grasping the glass. Start of drinking phase was detected when the linear hand velocity crossed the zero value upwards in the medial (-) / lateral (+) direction. Start of backward transport phase was defined as the time when linear hand velocity crossed the zero value downwards in the cephalic (+) / caudal (-) direction. Start of the returning phase was detected when the linear hand velocity crossed the zero value downwards in the anterior (+) / posterior (-) direction. Movement offset was detected when the linear velocity of the hand crossed the zero value upwards in the posterior (-) / anterior (+) direction.

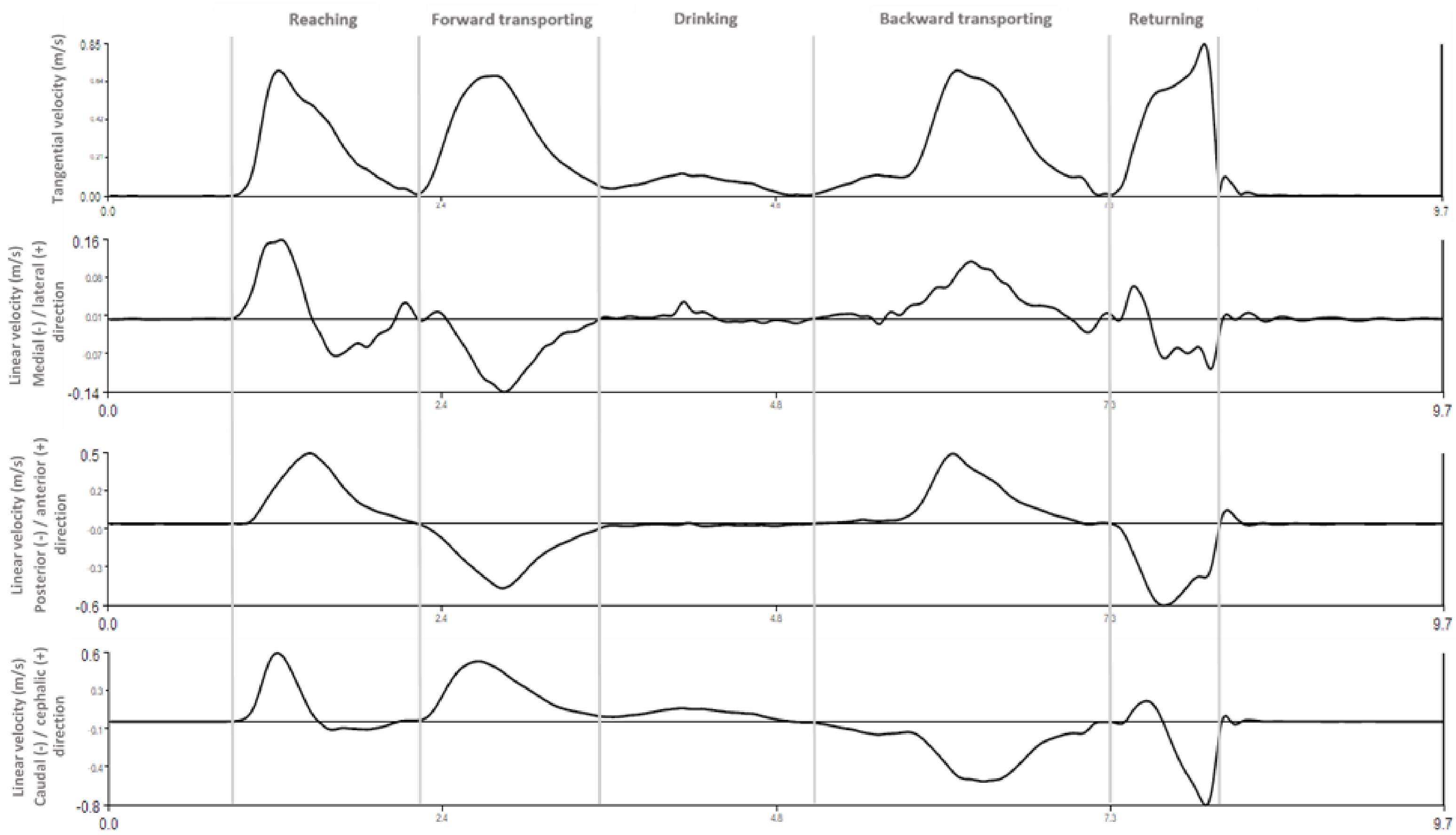


Figure 3. An example of phases definition of drinking task through hand's tangential velocity and hand's linear velocity in medial (-) / lateral (+), posterior (-) / anterior (+) and caudal (-) / cephalic (+) directions. The grey vertical lines are the event lines dividing the phases of the drinking task.

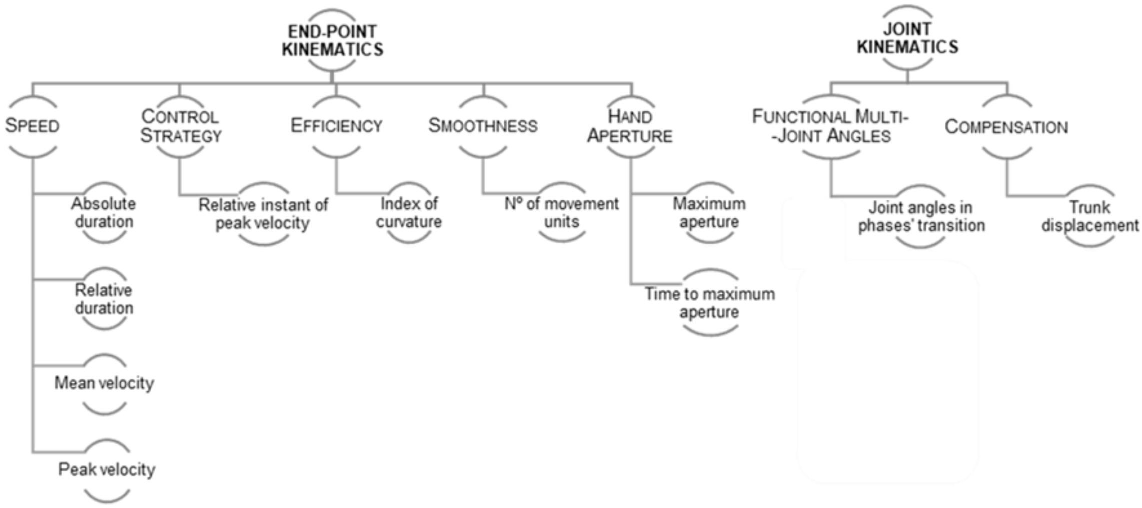


Figure 4. Metrics obtained from end-point and joint kinematic data and the characteristic of movement they represent, according to de los Reyes-Guzmán et al. (2014).

Figure 4 represents the kinematic metrics analysed and the component of movement they characterize:

- **Absolute duration** and **relative duration** were calculated for each phase;
- **Mean velocities** and **peak velocities** were determined for each phase from tangential velocity of the hand;
- **Relative instant of peak velocity** was calculated for each phase (except for drinking phase) from tangential velocity of the hand. This variable allows to measure the acceleration and deceleration periods, i.e., the control strategy used during the movement (de los Reyes-Guzmán et al., 2014);
- **Index of curvature** was determined for each phase (except drinking phase) through the calculation of the ratio of the path length and the line-of-sight distance between the initial to the final endpoint position. Values closed to 1.0 are representative of shorter hand trajectory during movement, i.e. an efficient movement (de los Reyes-Guzmán et al., 2014);
- **Number of movement units** (velocity peaks) was calculated for each phase, with a movement unit considered as the difference between a minimum and next maximum velocity value (of the tangential velocity profile of the hand) that exceeds the amplitude limit of 0.02 m/s. The time

between 2 subsequent peaks had to be at least 0.15 seconds. A custom analysis routine was developed in Matlab R2014a (The MathWorks Inc. Massachussets, USA) for this calculations. A smoother movement has only one peak in the velocity profile of the hand movement (de los Reyes-Guzmán et al., 2014);

- **Joint angles in each phase transition** (and minimum and maximum angles to complement descriptive analysis) of shoulder flexion (+) / extension (-), shoulder adduction (+) / abduction (-), shoulder medial rotation (+) / lateral rotation (-), elbow flexion (+) / extension (-), elbow pronation (+) / supination (-), wrist flexion (+) / extension (-), and wrist ulnar deviation (+) / radial deviation (-);
- **Absolute maximum magnitude of hand aperture** (maximum distance between the thumb and index finger markers) (Patterson et al., 2011) and relative instant of maximum hand aperture during the reaching and returning phases. These variables allow to measure the pre-shaping strategy during the reaching phase, and the release of the glass strategy during the returning phase;
- **Trunk displacement** was determined through the difference between the end position of the trunk's center of mass at each phase, and its start position, in the sagittal, frontal and transverse planes. In sagittal plane, trunk displaced in anterior (+) and/or posterior (-) directions, in frontal plane trunk displaced in ipsilateral (+) and/or contralateral (-) directions, and in transverse plane trunk displaced in upwards (+) and/or downwards (-).

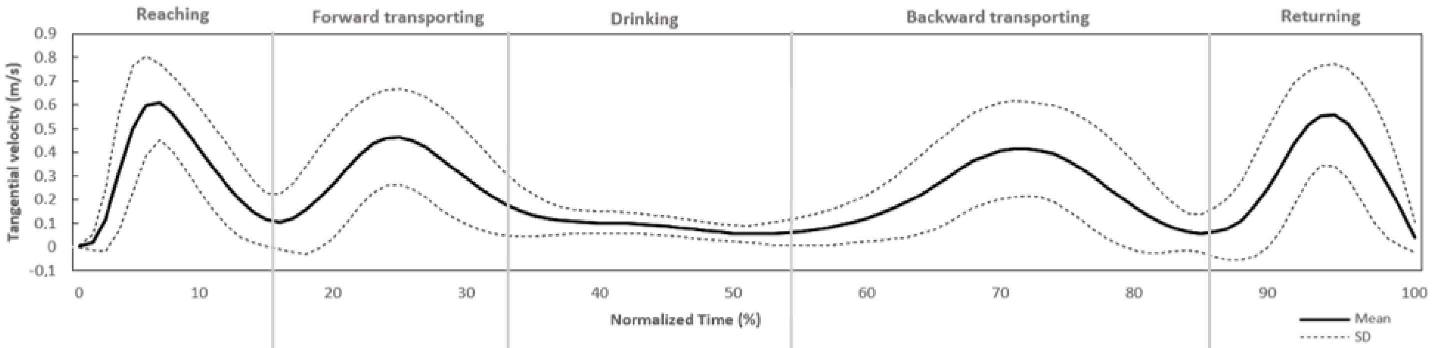
These kinematic metrics were calculated in all trials.

2.5. Statistical analysis

Following the data processing, the statistical analysis was carried out using Statistica 13 software (TIBCO Software Inc, Palo Alto - CA, USA). The mean of the three trials of each participant was considered for statistical analysis. Outliers were identified using 2 standard deviation approach, and the values were replaced by central tendency. Descriptive statistics was performed using mean, standard deviation and frequency distribution. All the prerequisites for analysis of variance were met (normality, homogeneity and sphericity). A Multifactorial Analysis of Variance was used, having as main factors: age category (30-55 years old, 56-74 years old, according to SRRR's recommendations (Kwakkel et al., 2017)), sex (female, male), BMI category (normal, overweight) and dominance (dominant UL, non-dominant UL). Interaction effects were identified by a Fisher post-hoc test and the effect sizes through the partial η^2, according to Cohen's guidelines (0.01=small; 0.06=medium; and 0.14=large effect) (Pallant, 2007). To avoid the possibility of inferring the existence of differences that do not really exist (type one error), we only considered relevant to report those that were associated with medium or large effect sizes. A significance level of 0.05 was used for all tests.

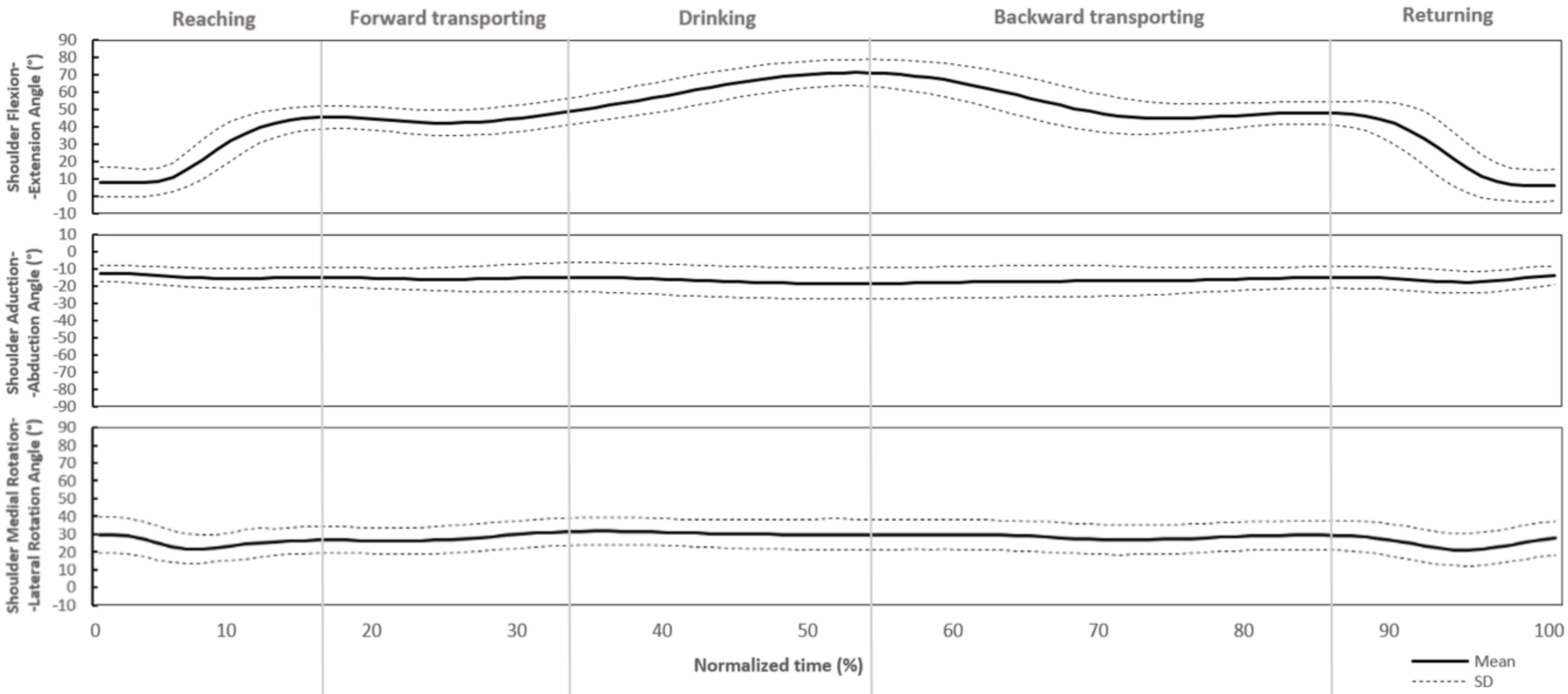
3. Results

The normalized tangential velocity profile of the hand, and the normalized time histories of the joint angles are displayed in the figures 5, 6 and 7, respectively. Below figures 5 and 6 are the respective kinematics with the exerted effects presented. Table 2 presents elbow and wrist angles during each offset phase and table 3 presents trunk displacement in sagittal, frontal and transverse planes, during each phase of drinking task. Presented values refer to the mean and standard deviation of the total sample (dominant and non-dominant ULs) or of sample groups in the kinematic metrics in which were found statistically significant differences with medium or large effects.



END-POINT KINEMATICS	**Absolute duration (s)**	1.342 ± 0.269	30-55 y. old: 1.230 ± 0.210 56-74 y. old: 1.441 ± 0.252	30-55 y. old: 1.586 ± 0.514 56-74 y. old: 2.027 ± 0.667	30-55 y. old: 2.460 ± 0.411 56-74 y. old: 2.764 ± 0.455	1.095 ± 0.226
	Relative duration (%)	16.9 ± 2.3	F: 15.8 ± 1.7 M: 16.7 ± 1.6	16.2 ± 1.7	F: 32.7 ± 3.1 M: 31.4 ± 2.8	13.8 ± 2.3
	Mean velocity (m/s)	0.289 ± 0.056	30-55 y. old: 0.358 ± 0.058 56-74 y. old: 0.287 ± 0.054	30-55 y. old: 0.085 ± 0.027 56-74 y. old: 0.066 ± 0.021	30-55 y. old: F: 0.221 ± 0.042; M: 0.251 ± 0.052 56-74 y. old: F: 0.159 ± 0.045; M: 0.224 ± 0.041	0.354 ± 0.070
	Peak velocity (m/s)	0.744 ± 0.140	30-55 y. old: 0.676 ± 0.118 56-74 y. old: 0.554 ± 0.127	30-55 y. old: 0.144 ± 0.044 56-74 y. old: 0.113 ± 0.030	30-55 y. old: F: 0.625 ± 0.086; M: 0.720 ± 0.164 56-74 y. old: F: 0.484 ± 0.096; M: 0.627 ± 0.110	0.744 ± 0.135
	Relative instant of Peak velocity (%)	32.5 ± 5.3	36.4 ± 4.8	--	51.3 ± 5.6	52.2 ± 10.4
	Index of curvature	1.340 ± 0.134	D limb: 1.017 ± 0.007 ND limb: 1.022 ± 0.010	--	1.064 ± 0.032	1.299 ± 0.119
	Number of movement units	1.2 ± 0.3	1.0 ± 0.0	1.2 ± 0.4	2.5 ± 0.7	1.5 ± 0.4
	Maximum Magnitude of Hand Aperture (m)	0.119 ± 0.009				30-55 y. old: 0.117 ± 0.009 56-74 y. old: 0.110 ± 0.008
	Relative instant of Maximum Hand Aperture (%)	67.6 ± 7.6				26.0 ± 6.7

Figure 5. Normalized time history of hand's tangential velocity during drinking task and respective end-point kinematics. The presented values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of groups of the sample in the variables in which were found statistically significant differences with medium or large effects. The grey vertical lines are the event lines to distinguish the phases of the drinking task. D: Dominant; F: Female; M: Male; ND: Non-dominant; SD – Standard deviation; y. old: years old.



JOINT KINEMATICS	Shoulder Flexion-Extension Offset angle (°)	46.5 ± 6.3	49.7 ± 7.0	73.5 ± 7.0	48.5 ± 6.4	6.2 ± 8.8
	Shoulder Adduction-Abduction Offset angle (°)	D limb: -16.1 ± 5.2	F: D limb: -16.4 ± 8.5 F: ND limb: -9.4 ± 8.6	D limb: -21.5 ± 7.7	D limb: -16.1 ± 5.5	Normal BMI: -11.7 ± 4.7
		ND limb: -13.3 ± 5.9	M: -16.2 ± 7.7	ND limb: -16.3 ± 10.0	ND limb: -13.6 ± 7.0	Overweight: -15.8 ± 5.2
	Shoulder Medial rotation-Lateral rotation Offset angle (°)	26.8 ± 7.5	32.1 ± 7.8	29.7 ± 8.1	29.7 ± 8.3	Normal BMI: 28.0 ± 7.6 Over-weight F: 33.2 ± 7.7 Over-weight M: 21.8 ±7.4

Figure 6. Normalized time history of shoulder angle during drinking task and respective joint kinematics. The presented values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of groups of the sample in the variables in which were found statistically significant differences with medium or large effects. The grey vertical lines are the event lines to distinguish the phases of the drinking task. D: Dominant; F: Female; M: Male; ND: Non-dominant; SD – Standard deviation.

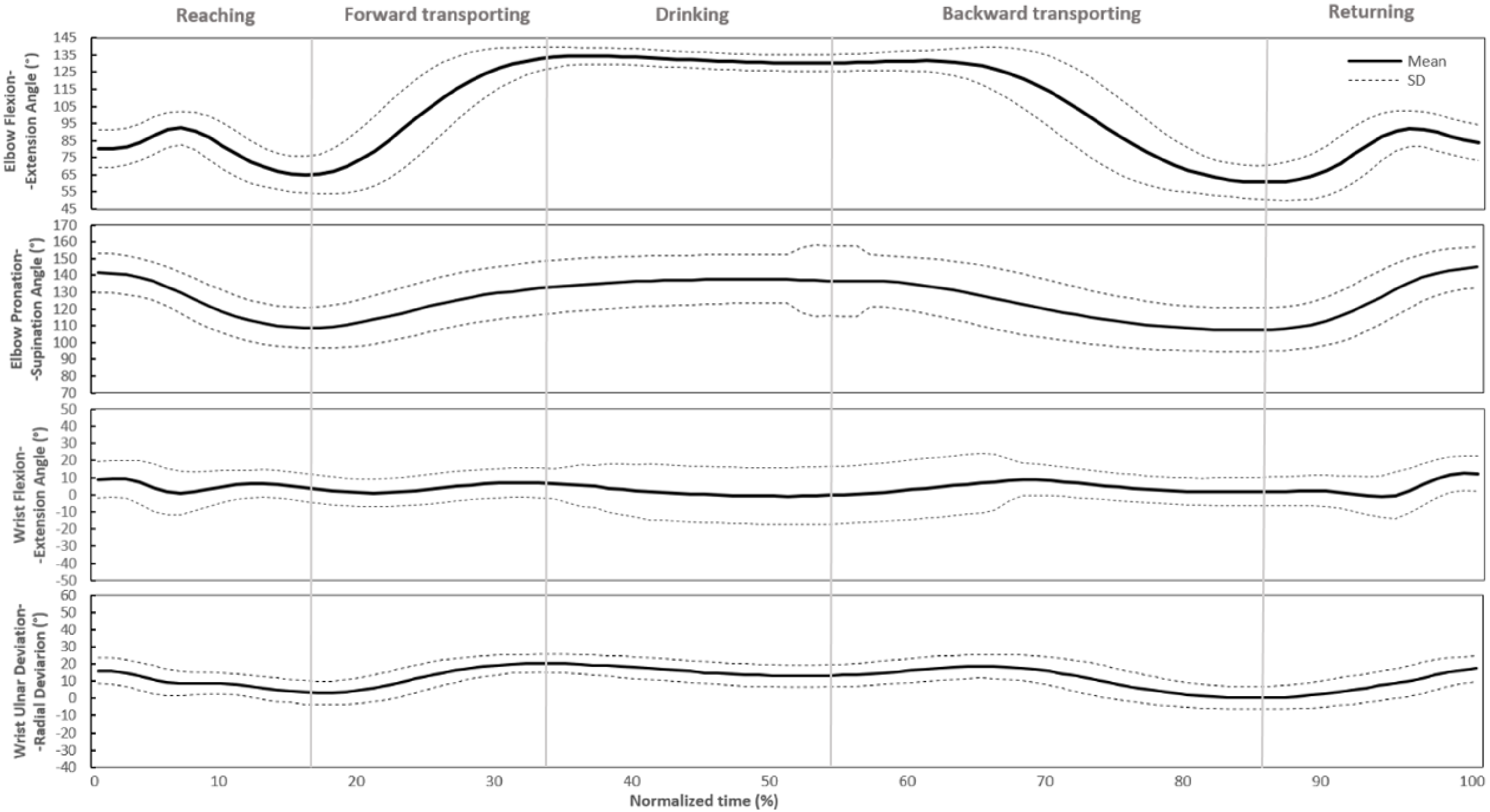


Figure 7. Normalized time history of elbow and wrist angles during drinking task and respective joint kinematics. The grey vertical lines are the event lines to distinguish the phases of the drinking task. SD – Standard deviation

Table 2 – Elbow and wrist angles in each offset phase of drinking task. Mean ± standard deviation.

<table>
<tr><th>Joint Kinematics / Phases</th><th>Reaching</th><th>Forward transporting</th><th colspan="2">Drinking</th><th>Backward transporting</th><th colspan="2">Returning</th></tr>
<tr><td rowspan="3">Elbow Flexion-Extension Offset angle (°)</td><td rowspan="2">F: 65.9 ± 9.3</td><td rowspan="2">F: 137.2 ± 4.4</td><td colspan="2" rowspan="3">129.9 ± 5.0</td><td rowspan="2">F: 61.3 ± 9.6</td><td rowspan="2">Normal BMI</td><td>F: 85.0 ± 8.1</td></tr>
<tr><td>M: 71.6 ± 13.7</td></tr>
<tr><td>M: 57.7 ± 8.6</td><td>M: 133.4 ± 3.8</td><td>M: 55.2 ± 8.2</td><td colspan="2">Overweight: 85.2 ± 9.4</td></tr>
<tr><td rowspan="2">Elbow Pronation-Supination Offset angle (°)</td><td>30-55 y. old: 109.5 ± 10.9</td><td>30-55 y. old: 136.8 ± 14.8</td><td colspan="2">30-55 y. old: 140.5 ± 13.0</td><td>30-55 y. old: 109.6 ± 11.7</td><td colspan="2" rowspan="2">144.2 ± 12.2</td></tr>
<tr><td>56-74 y. old: 101.2 ± 11.5</td><td>56-74 y. old: 124.7 ± 14.3</td><td colspan="2">56-74 y. old: 131.3 ± 14.4</td><td>56-74 y. old: 101.5 ± 13.5</td></tr>
<tr><td rowspan="3">Wrist Flexion-Extension Offset angle (°)</td><td>F: 4.1 ± 7.1</td><td>F: 10.3 ± 7.2</td><td colspan="2">F: 2.5 ± 8.5</td><td>F: 3.5 ± 7.5</td><td colspan="2">D limb: 15.1 ± 9.8</td></tr>
<tr><td rowspan="2">M: 0.1 ± 7.9</td><td rowspan="2">M: 2.0 ± 7.8</td><td colspan="2" rowspan="2">M: -3.5 ± 7.5</td><td rowspan="2">M: -1.0 ± 8.0</td><td rowspan="2">ND limb</td><td>F: 12.1 ± 10.9</td></tr>
<tr><td>M: 5.5 ± 7.6</td></tr>
<tr><td rowspan="4">Wrist Ulnar Deviation- -Radial Deviation Offset angle (°)</td><td rowspan="4">2.1 ± 5.4</td><td rowspan="4">21.3 ± 5.0</td><td rowspan="2">30-55 y. old</td><td>D limb: 15.0 ± 5.5</td><td rowspan="4">0.0 ± 6.5</td><td colspan="2" rowspan="4">17.5 ± 7.2</td></tr>
<tr><td>ND limb: 11.7 ± 6.5</td></tr>
<tr><td rowspan="2">56-74 y. old</td><td>D limb: 11.9 ± 5.7</td></tr>
<tr><td>ND limb: 6.7 ± 7.0</td></tr>
</table>

The presented values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of groups of the sample in the variables in which were found statistically significant differences with medium or large effects. The grey vertical lines are the event lines to distinguish the phases of the drinking task. D: Dominant; F: Female; M: Male; ND: Non-dominant.; y. old: years old.

Table 3 – Trunk displacement (m) in sagital, frontal and transverse planes, during each phase of drinking task. Mean ± standard deviation.

Planes / Phases	*Reaching*	*Forward transporting*	*Drinking*	*Backward transporting*	*Returning*
Sagittal	0.013 ± 0.011	-0.010 ± 0.008	-0.002 ± 0.004	0.010 ± 0.007	-0.008 ± 0.009
Frontal	30-55 y. old: 0.001 ± 0.004 56-74 y. old: 0.004 ± 0.004	-0.002 ± 0.004	-0.002 ± 0.002	30-55 y. old: 0.004 ± 0.003 56-74 y. old: 0.005 ± 0.003	-0.002 ± 0.004
Transverse	30-55 y. old: 0.001 ± 0.002 56-74 y. old: 0.003 ± 0.002	0.002 ± 0.002	0.004 ± 0.002	-0.006 ± 0.002	-0.002 ± 0.002

3.1. End-point kinematics

3.1.1 Speed

The longest phase of the task was the backward transporting (2.547 ± 0.444 s; 32.2 ± 3.0 %), followed by the drinking (1.712 ± 0.594 s; 20.9 ± 4.5 %), the reaching (1.342 ± 0.269 s; 16.9 ± 2.3 %), the forward transporting (1.290 ± 0.242 s; 16.2 ± 1.7 %) and, finally, the returning phase (1.095 ± 0.226 s; 13.8 ± 2.3 %). Age and sex exerted effect on absolute duration and relative duration of some phases, respectively. Older adults (56-74 years old) took a longer time than younger adults (30-55 years old) to perform forward transporting ($p<0.01$; $F(1,110)=21.84$; partial $\eta^2=0.17$), drinking ($p<0.01$; $F(1,110)=11.45$; partial $\eta^2=0.09$) and backward transporting ($p<0.01$; $F(1,110)=12.63$; partial $\eta^2=0.10$), with a large effect of age factor being noticed in the absolute duration of forward transporting. Women took less time than men ($p<0.01$; $F(1,110)=9.16$; partial $\eta^2=0.08$) in forward transporting, and men took less time than women ($p<0.01$; $F(1,110)=10.19$; partial $\eta^2=0.08$) performing backward transporting.

The fastest phase of the task was the returning (0.354 ± 0.070 m/s), followed by the forward transporting (0.338 ± 0.066 m/s), the reaching (0.289 ± 0.056 m/s), the backward transporting (0.219 ± 0.054 m/s) and, finally, the drinking phase (0.080 ± 0.027 m/s). The phases in which the higher peak velocities were observed were those of reaching (0.744 ± 0.140 m/s) and returning (0.744 ± 0.135 m/s), followed by the forward transporting (0.641 ± 0.132 m/s), the backward transporting (0.627 ± 0.140 m/s) and the drinking phase (0.135 ± 0.043 m/s). Age exerted effect on mean and maximum velocities of the drinking and transporting phases: younger adults presented higher mean and peak velocities than older adults in forward transporting (mean velocity: $p<0.01$; $F(1,110)=28.84$; partial $\eta^2=0.21$; peak velocity: $p<0.01$; $F(1,110)=11.47$; partial $\eta^2=0.09$), drinking (mean velocity: $p<0.01$; $F(1,110)=11.56$; partial $\eta^2=0.10$; peak velocity: $p<0.01$; $F(1,110)=10.14$; partial $\eta^2=0.08$) and backward transporting (mean velocity: $p<0.01$; $F(1,110)=25.08$; partial $\eta^2=0.19$; peak velocity: $p<0.01$; $F(1,110)=17.62$; partial $\eta^2=0.14$). Sex had a large effect on mean and maximum velocities of the backward transporting, with men presenting higher mean and peak velocities than women (mean velocity: $p<0.01$; $F(1,110)=31.17$; partial $\eta^2=0.22$; peak velocity: $p<0.01$; $F(1,110)=20.51$; partial $\eta^2=0.16$).

3.1.2 Control strategy

The peak velocity occurred earlier in the reaching (32.5 ± 5.3 %), followed by the forward transporting (36.4 ± 4.8 %), the backward transporting (51.3 ± 5.6 %) and the returning (52.2 ± 10.4 %). None of the analysed factors had an effect on this variable.3.1.3 Efficiency

The lowest index of curvature was observed in the forward transporting phase (1.019 ± 0.009), followed by the backward transporting (1.064 ± 0.032), the returning (1.299 ± 0.119), and the reaching (1.340 ± 0.134). Only dominance exerted a medium effect on forward transporting, with the dominant UL presenting a lower index of curvature than non-dominant UL ($p<0.01$; $F(1,110)=11$; partial $\eta^2=0.09$).

3.1.4 Smoothness

The lowest number of movement units was observed in the forward transporting phase (1.0 ± 0.0), followed by the reaching (1.2 ± 0.3) and the drinking (1.2 ± 0.4) phases, the returning (1.5 ± 0.4), and the backward transporting (2.5 ± 0.7). None of the analysed factors had an effect on this variable.

3.1.5 Hand aperture

The maximum magnitude of the hand aperture was slightly higher in the reaching (0.119 ± 0.009 m) compared to the returning (0.115 ± 0.009 m) phase. In this last phase, younger adults opened their hands wider than the older ones ($p<0.01$; $F(1,110)=11.38$; partial $\eta^2=0.09$).

The relative instant at which this occurred was significantly different in the reaching (67.6 ± 7.6 %) and returning (26.0 ± 6.7 %) phases. None of the analysed factors had an effect on this last variable.

3.2 Joint kinematics

3.2.1 Shoulder angles

At the shoulder, a greater range of motion was observed in the sagittal plane, with the minimum angle of flexion being observed at the beginning (6.1 ± 7.3 °) and at the end of the task (3.7 ± 8.4 °), and the maximum angle occurring in the transition between drinking and backward transporting (73.5 ± 7.2 °).

The second largest range of motion was recorded in the transverse plane, with the minimum angle of medial rotation being registered during reaching (18.8 ± 7.7 °) and returning (16.4 ± 8.4 °) phases, and the maximum angle during the drinking phase (33.0 ± 8.2 °). Sex and its interaction with BMI exerted effect on the medial rotation angle of the shoulder at the end of the task ($p<0.01$; $F(1,110)=9.36$; partial $\eta^2=0.08$ and $p<0.01$; $F(1,110)=13.33$; partial $\eta^2=0.11$, respectively). Overweight women presented the highest shoulder medial rotation angles (33.2 ± 7.7 °) and overweight men presented the lowest ones (21.8 ± 7.4°).

Finally, in the frontal plane, the minimum angle of adduction was recorded in the transition between drinking and backward transporting (-20.8 ± 8.5 °) and the maximum angle occurred in the beginning of the task (-11.5 ± 5.0 °). Dominance exerted effect in almost all phases (with the exception of the returning), with the dominant UL presenting lower shoulder aduction angles than the non-dominant UL at the offset of: reaching ($p<0.01$; $F(1,110)=14.25$; partial $\eta^2=0.11$), forward transporting ($p<0.01$; $F(1,110)=13.47$; partial $\eta^2=0.11$), drinking ($p<0.01$; $F(1,110)=10.92$; partial $\eta^2=0.09$) and backward transporting ($p<0.01$; $F(1,110)=9.15$; partial $\eta^2=0.08$). Men presented lower shoulder adduction angles than women, particularly their non-dominant UL ($p<0.01$; $F(1,110)=7.14$; partial $\eta^2=0.06$), at the offset of forward transporting. Overweight adults completed the task at a lower shoulder adduction angles than the adults with normal BMI ($p<0.01$; $F(1,110)=16.17$; partial $\eta^2=0.13$).

3.2.2 Elbow angles

At the elbow, a greater range of motion was also observed in the sagittal plane, with the minimum angle of flexion being observed at the transition between backward transport and the returning (58.9 ± 9.5 °), and the maximum angle occurring in the transition between forward transporting and drinking (135.7 ± 4.5°). Sex exerted effect in almost all phases (with the exception of the drinking phase), with men presenting lower elbow flexion angles than the women at the offset of: reaching ($p<0.01$; $F(1.110)=16.42$; partial $\eta^2=0.13$), forward transporting ($p<0.01$; $F(1,110)=12.50$; partial $\eta^2=0.10$), backward transporting ($p<0.01$; $F(1,110)=9.12$; partial $\eta^2=0.08$) and returning ($p<0.01$; $F(1,110)=16.13$; partial $\eta^2=0.13$). The angle of elbow flexion at the end of the task was also influenced by BMI: adults with normal BMI, particularly men, completed the task with smaller angle of elbow flexion than overweight adults ($p<0.01$; $F(1,110)=12.65$; partial $\eta^2=0.10$).

In the transverse plane, the minimum angle of pronation was recorded at the offset of reaching (107.1 ± 11.6 °) and of backward transporting (107.3 ± 12.8 °) and the maximum angles were observed at the onset (144.2 ± 12.2 °) and the offset (141.2 ± 11.5 °) of the task. Older adults presented lower elbow pronation angles than the younger ones in almost all phases, except in the returning: reaching ($p<0.01$; $F(1,110)=15.04$; partial $\eta^2=0.12$), forward transporting ($p<0.01$; $F(1,110)=13.70$; partial $\eta^2=0.11$), drinking ($p<0.01$; $F(1,110)=10.43$; partial $\eta^2=0.09$) and backward transporting ($p<0.01$; $F(1,110)=9.26$; partial $\eta^2=0.08$).

3.2.3 Wrist angles

In the wrist, a greater range of motion was observed in the frontal plane, with the minimum angle of ulnar deviation being observed at the transition between backward transporting and returning phase (0.0 ± 6.5 °), and the maximum angle occurring in the transition between forward transporting and drinking (21.3 ± 5.0 °) and during backward transporting (22.5 ± 5.2 °). Younger adults presented higher ulnar deviation angles than older ones at the transition between drinking and backward transporting ($p<0.01$; $F(1,110)=7.80$; partial $\eta^2=0.07$), as well as higher maximum ulnar deviation angles during backward transporting ($p<0.01$; $F(1,110)=11.23$; partial $\eta^2=0.09$). At the end of drinking phase, dominant UL presented also higher ulnar deviation angles than non-dominant UL ($p<0.01$; $F(1,110)=13.40$; partial $\eta^2=0.11$).

In the sagittal plane, the minimum (-9.6 ± 12.0 °) and the maximum (17.2 ± 12.9 °) angles of flexion were recorded during returning. Sex exerted effect in all phases, with men presenting lower wrist flexion angles than the women at the offset of: reaching ($p<0.01$; $F(1,110)=15.96$; partial $\eta^2=0.13$), forward transporting ($p<0.01$; $F(1,110)=32.3$; partial η^2=0,.23), drinking ($p<0.01$; $F(1,110)=21.0$; partial $\eta^2=0.16$), backward transporting ($p<0.01$; $F(1,110)=17.14$; partial $\eta^2=0.13$) and returning ($p<0.01$; $F(1,110)=13.70$; partial $\eta^2=0.11$). In addition, men and older adults presented lower wrist maximum angles during backward transporting than women ($p<0.01$; $F(1,110)=34.50$; partial $\eta^2=0.24$) and younger adults ($p<0.01$; $F(1,110)=12.46$; partial $\eta^2=0.10$), respectively. At the end of the task, non-dominant UL assumed also a lower wrist flexion angle than dominant UL ($p<0.01$; $F(1,110)=9.35$; partial $\eta^2=0.08$).

3.2.4 Trunk displacement

The plane in which a greater displacement of the trunk was observed was the sagittal, in which there were displacements equal to or greater than 0.010 meters in reaching (0.013 ± 0.011 m), in forward transporting (-0.010 ± 0.008 m) and in backward transporting (0.010 ± 0.007 m). Older adults presented greater displacements than younger ones in reaching of frontal ($p<0.01$; $F(1,110)=10.25$; partial $\eta^2=0.09$) and transverse ($p<0.01$; $F(1,110)=8.66$; partial $\eta^2=0.07$) planes, as well as the backward transporting in the frontal plane ($p<0.01$; $F(1,110)=10.64$; partial $\eta^2=0.09$).

4. Discussion

In this article, it was studied the drinking task performed by healthy adults, through the analysis of end-point and joint kinematics. No other study about drinking, as far as we know, analysed: a) this set of variables in all phases of the task; b) the hand aperture; c) the joint angles of the shoulder, elbow and wrist in the phases transitions; d) and trunk displacement in frontal and transverse planes. In addition, no other study normalized the base of support and the glass location to the anthropometric characteristics of each participant. This normalization is important to ensure that task environment is not the responsible for variability in the kinematic metrics analysed. Therefore, the comparison of our data with other previous studies was limited but made whenever relevant.

As this task can be divided into five phases with such distinct kinematic strategies that can be transposed to other ADLs, it becomes relevant to discuss their main characteristics separately. The observed effects exerted by age, sex, BMI and UL dominance on studied kinematics are discussed in the final section.

4.1 Reaching

In drinking task, the intention of reaching movement is to grasp a glass. It is important to remember that, according to literature (Shumway-Cook & Woollacott, 2017), reaching vary according to the goals (e.g. grasping or pointing) and constraints (position, distance and dimension of the object, postural demands, etc.) of the task. We have chosen to place the glass in the participant's visual field and at a lesser distance than total length of the UL, to decrease the need to move the eyes and the head, as well as the trunk, respectively (Shumway-Cook & Woollacott, 2017). This option made it possible to focus on the role of the UL. In addition, we have also chosen a seated reaching task to decrease the postural requirements from the lower limbs (Shumway-Cook & Woollacott, 2017), however without support of trunk to be able to evaluate its possible displacement, as a compensatory strategy. Finally, we chose to start and finish the task with the hand resting downwards on the ipsilateral thigh, and not on the table like other studies (Kim et al., 2014; Murphy et al., 2006; Murphy et al., 2011), to allow comparison of this task with other ADL, which generally do not involve the previous support of the UL on a surface.

In the present study, the reaching movement presented an intermediate duration (absolute and relative) and mean velocity, compared to the other phases of the task. In Kim et al. study (2014), reaching was the second shortest phase, in the healthy group, and presented about half the absolute duration of the reaching, when compared to our study. According to Fitt’s law (Fitts, 1954), movement duration is mainly affected by the distance moved, and by the width of the target. Narrower target widths and longer distances contribute to slowing the speed of the task (Shumway-Cook & Woollacott, 2017). As Kim et al. (2014) did not indicate the dimensions of the glass, nor its location in space, it is not possible to infer which of the factors produced this difference.

Despite this, in our study, such as in study of Murphy et al. (2006), along with the returning phase, reaching showed the highest peak velocity. This may result from the fact that these two phases do not involve the glass transport or handling and, therefore, do not require such an efficient and precise trajectory, allowing the achievement of higher speeds. This theory agrees with the value of the index of curvature (efficiency measure), which shows that these phases were the least efficient.

Nevertheless, the hand's trajectory in reaching was one of the smoothest, with an average of one peak velocity (unit of movement). Unlike other studies (Murphy et al., 2018; Murphy et al., 2011) in which peak velocity happened approximately in the middle of reaching, in our study, it occurred approximately at the end of the first third of this phase, indicating a longer time in the deceleration phase. While generally a longer deceleration period is attributed to a more demanding reaching goal (Shumway-Cook & Woollacott, 2017), since it was the same (drinking) and the object too, it is important that future studies examine whether the location and distance of the target affect the velocity profile.

During reaching, the UL movement carrying the hand to the target is performed in parallel with the pre-shaping of the fingers for grasping the object (Shumway-Cook & Woollacott, 2017). To analyse pre-shaping, we have studied the maximum magnitude of hand aperture preceding the grasp of the glass, as well as the moment at which this occurs. Although these variables have already been studied in other tasks (Patterson et al., 2011; Wallace, Weeks, & Kelso, 1990), no other study, to the best of our knowledge, has examined this ability in drinking. In this study, the maximum magnitude of hand aperture was approximately 11.9 cm. According to Castiello (2005), the grip size increases to a maximum and then is reduced to match the size of the object, which is also observed in our study, since the diameter of the glass is 7 cm (Castiello, 2005). The relative instant of maximum hand aperture occurred approximately at the end of the second third of reaching, which is also in agreement with the literature (Shumway-Cook & Woollacott, 2017) that indicates that it occurs during the final-slow-approach phase. For future studies, it is important not to forget that pre-shaping is affected by the properties of the object, namely its size, shape and texture (intrinsic properties) and its orientation, distance and location with respect to the body (extrinsic properties) (Jeannerod, 1984).

As the hand was below the level of the glass and this, in turn, was aligned with the ipsilateral hip, the hand had to be transported in the upward and forward direction to grasp the glass. As expected, the shoulder and the elbow seemed to be the principal effectors for this transport. Initially, there was a greater range of elbow flexion (raising the hand), and secondly, shoulder flexion and elbow extension allowed the hand to move forward. Although the location of the glass decreased the need for the trunk to move, it has moved significantly in the forward direction. In addition to hand’s transport, it was necessary that this segment, which started the task in a downward position, has taken the proper orientation to grasp the glass. Probably, this orientation has been achieved by the forearm supination and, also, by the subtle movements of lateral rotation and abduction of the shoulder, as well as by radial deviation and extension of the wrist, at an early stage. In the deceleration phase, gradually the shoulder and wrist angles approximated the initial medial rotation and flexion angles, respectively.

4.2 Forward transporting

Ensuring a correct hand trajectory becomes challenging at this stage. First, because the force of gravity and inertia to overcome are higher than in reaching, due to the additional transport of the glass. It is also necessary to ensure proper orientation of this object to avoid spilling water, and, perhaps even more challenging, the target for which the glass is transported, i.e. the mouth, is not visible (Maitra & Junkins, 2004). This increases the need to use proprioceptive information from the hand, UL and mouth to map the trajectory to be performed, in detriment of visual one (Maitra & Junkins, 2004). These factors may explain the intermediate value of its peak velocity and, like reaching, a longer deceleration period. Despite this, forward transporting was the more efficient and smoother phase, as well as the second phase shorter and faster. This may result from a decrease in the distance between the hand and the axes of rotation of the elbow and shoulder in the sagittal plane, thus reducing the torque required to produce movement. On the other hand, from the point of view of postural control, this movement represents an approximation of the center of mass to the center of the base of support, increasing the postural stability, and, consequently, the quality of movement (Shumway-Cook & Woollacott, 2017).

The trajectory of the hand to the mouth was mainly assured by the wide elbow flexion. The medial rotation of the shoulder allowed it to approach the midline of the body. In turn, the adequate glass orientation was achieved with forearm pronation, and wrist flexion and ulnar deviation. These movements were accompanied by the trunk displacement in the upper direction in the transverse plane, and its gradual return to the initial position of the task, in the sagittal and frontal planes.

In this phase and in the next two ones, we did not analyse any kinematics about glass grasping or manipulation because glass movements relative do the hand and within the hand are not expected in a power grip (Shumway-Cook & Woollacott, 2017) like grasping a glass (according to Napier’s classification (Napier, 1956)). However, in studies with tasks involving a precision grip, it will be necessary to analyse the movement of the thumb and fingers.

4.3 Drinking

In this phase the glass assumes an oblique orientation and the main purpose of the task was achieved. Perhaps for this reason, although the trajectory performed was short, this was the slowest phase, in addition to being one of the smoothest. We did not consider relevant to analyse the index of curvature or the relative instant of peak velocity in this phase, because the trajectory performed by the hand is very short during drinking.

The movements responsible for ensure the drink of water were: shoulder flexion and abduction, forearm pronation, and wrist radial deviation and extension. Since the angles of shoulder flexion and abduction are the maximum angles of the task, some authors (Murphy et al., 2006; Murphy et al., 2011) have also analysed these angles in this phase. However, their angles of shoulder flexion and abduction were significantly lower and higher (respectively) than the ones found in the present study. As the age range covered was similar to this article, we thought that this might result from the sample being significantly smaller than ours, or from the fact that the history of neuro-musculoskeletal pathologies has not been scrutinized. This last factor could affect shoulder flexion and consequently increase abduction as a compensatory strategy to accomplish the task.

In the sagittal and frontal planes, the gradual return of the trunk to the position of the beginning of the task is completed in this phase, while in the transverse plane this segment continues to move in the upper direction. Possibly, this displacement in the upper direction (started in the previous phase) aimed to improve postural control of the trunk and consequently to secure the stability of head and mouth (the main target of this task and of this specific phase).

Therefore, although trunk displacement, in the sagittal plane, is generally considered to be only a strategy used to compensate the decrease in shoulder and / or elbow mobility, it is necessary to explore other roles of trunk displacement, namely in transverse plane, possibly as a stability synergist of the body's target.

4.4 Backward transporting

After drinking a sip of water, the glass was transported to the base on which it was initially laid. This basis served to ensure the normalization of the target at this stage. We have considered that this transport ended when the glass was placed on the base. Other authors (Murphy et al., 2018) included in this phase the release of the glass, which in our study was considered part of the returning phase.

As in other studies (Kim et al., 2014; Murphy et al., 2006), this was the longest phase of the task. This was also the least smooth. Unlike forward transporting, in backward transporting there is an increase in the distance between the hand and the axes of rotation of the elbow and shoulder in the sagittal plane, thus increasing the torque required to produce movement. Here, center of mass moves away from the center of the base of support, reducing postural stability, which can compromise the quality of movement (Shumway-Cook & Woollacott, 2017). Moreover, this transport is mainly ensured by an eccentric contraction of the biceps, which is more demanding to control by CNS than a concentric one (Yao et al., 2017).

To facilitate these movement challenges, it is possible that the anterior and ipsilateral trunk displacement, more pronounced in this phase, has been used as a compensatory strategy.

Nevertheless, along with the forward transporting, this was one of the most efficient phases, which may indicate that the CNS ensures a more efficient trajectory when transporting objects. This can result from a significant increase in proprioceptive information from hand contact with the glass, which optimizes the feedback to improve motor pattern (in posterior parietal cortex) (Bolognini & Maravita, 2007), making the trajectory more straight.

Along with the returning phase, the acceleration and deceleration periods were approximately symmetrical. This may result from less challenging goals of these two phases (placing the glass on the base and returning to the initial position) compared to the reaching and forward transporting phases. On the other hand, in these last two phases the hand carries a downward trajectory (taking advantage of gravity) which may explain longer acceleration periods. It is necessary that future studies study the various factors that may influence the instant the peak velocity occurs.

To place the glass with the necessary orientation so that it did not tip over, the following movements were fundamental: supination of the forearm and radial deviation of the wrist.

4.5 Returning

After placing the glass on the table, it was necessary to release it to return to the starting position. Since this is generally a difficult movement for poststroke adults, we considered relevant to analyse the magnitude and the relative instant of the maximum hand aperture. It was possible to verify that the magnitude was slightly lower than the one that anticipated the grasping of the glass in reaching phase and that this occurred approximately 0.285 s after the beginning of the returning. After releasing the glass, this was probably the easiest path of the hand, since the target (the thigh) was the least demanding. Perhaps, for this reason this was the shortest and fastest phase of the task.

4.6 Effects of age, sex, upper limb dominance and body mass index

Age was the factor with the greatest impact on more kinematics and more drinking phases. The older adults took longer and were slower than the younger ones in the phases involving glass transport and drinking. Maitra & Junkins (2004), who compared the transport phases of drinking between nine young adults and nine older adults, also obtained these findings (Maitra & Junkins, 2004). Different systems could contribute to the slowing with aging, namely: a) the sensory and perceptual systems, such as the visual system; b) central processing systems; c) motor systems, and d) arousal and motivational systems (Welford, 1982). However, in the study of Maitra & Junkins (2004), older adults were faster in the backward transport than in the forward transport, which did not happen in our study. Furthermore, unlike the study of Maitra & Junkins (2004), age had no effect on smoothness or relative instant of peak velocity of transport. These differences could be related to the significant difference in sample size between the two studies.

The maximum magnitude of hand aperture in the returning phase was also lower in the older adult group, which may result of a decreased manual dexterity and mobility in this group (Shumway-Cook & Woollacott, 2017). Older adults had also lower angles of pronation in all transitions between phases, and, at the end of the drinking phase a lower angle of wrist ulnar deviation. These differences suggest that changes in hand orientation may also occur with age.

Finally, age was the only factor that exerted an effect on trunk displacement. In reaching, older adults used more ipsilateral and upward trunk displacement than younger ones, and in the backward transporting, the same happened in the frontal plane. This is compatible with changes in postural control, namely slowing in onset latencies for postural responses and in the use of feedback and feedforward control (Shumway-Cook & Woollacott, 2017).

Sex was the second factor with the greatest impact on the studied variables. Men took longer to forward transporting and at the end of this phase they presented a greater angle of abduction of the shoulder than the women. However in backward transporting the men took less time and were faster than women. These differences may result from sex difference in proportion of lean tissue distributed in the upper body, which is higher in men (Miller, MacDougall, Tarnopolsky, & Sale, 1993). This can cause an increased inertia during forward transporting and an increasing speed during backward transporting.

At the transition between phases, women had greater flexion of the wrist and in almost all (except at the end of the drinking phase) greater elbow flexion than men. At the end of the task, in addition to the greater flexion at the elbow and wrist level, the women presented greater medial rotation of the shoulder. A recent study (Nakatake et al., 2017) that looked at differences between sex during eating, also found that women presented higher maximum elbow flexion, when using a spoon and chopsticks. These authors also found that women presented smaller maximum wrist radial flexion and higher maximum shoulder medial rotation, when used chopsticks. It is important that future studies explore the multiple factors that may explain these differences (i.e. anthropometric characteristics, sensory-motor control, cultural reasons, etc.) and their impact on the transportation and orientation of the hand.

Surprisingly, dominance had effect on only a few variables. In forward transporting, the dominant UL was more efficient than the non-dominant UL. At the transition between phases, the dominant UL abducted more than the non-dominant UL. In addition, at the end of the drinking phase the dominant UL presented greater angle of ulnar deviation and at the end of the task, greater flexion of the wrist. Murphy et al. (2011) found differences between the dominant and non-dominant UL of healthy adults just in the magnitude of peak velocity, which was higher in the dominant UL. Sainburg suggested that dominant system is specialized in controlling limb trajectory and the non-dominant system in controlling limb position (Robert L. Sainburg, 2005). This hypothesis was supported by findings in his previous studies (Bagesteiro & Sainburg, 2002; R. L. Sainburg, 2002; R. L. Sainburg & Kalakanis, 2000) in which regardless of the less efficient trajectories of the non-dominant UL, final positions are often similar or even more accurate than that of the dominant UL. Our findings may be explained by this theory. However, this author has analysed only reaching movements with no functional purpose. Future studies should try to understand whether the conclusions of Sainburg also occur in ADLs.

Finally, the body mass index only had effect at the end of the task: overweight adults completed the task at a lower shoulder adduction angles than the adults with normal BMI and the latter, particularly men, completed the task with smaller angle of elbow flexion than overweight adults. It was expected to find a more significant effect throughout the task, since changes in the position and movement of the scapula in the rib cage were already found in subjects with higher BMI, during UL elevation (Gupta, Dashottar, & Borstad, 2013). Despite this little effect, the anthropometric measures continue to be important not only for the characterization of the sample but also for the normalization of the environment, according to them.

5. Conclusion

In this article, a comprehensive kinematic characterization of the drinking task performed by healthy adults was made, in order to obtain a reference of drinking performance for poststroke adults. End-point and joint kinematics analysis allowed to know the different kinematic strategies used in each phase of the task with their specific motor skills. Backward transporting was the longest phase and the returning was the fastest one. Peak velocity occurred earlier in reaching and forward transporting phases and later in backward transporting and returning phases. Forward transporting was the most efficient and smoothest phase. Maximum magnitude of the hand aperture was slightly higher and late in reaching phase compared with returning phase. Greater ranges of motion were observed in the sagittal plane of the shoulder and elbow and in the frontal plane of the wrist. Trunk also moved mainly in the sagittal plane. In addition, it was found that age and sex had significant effects on some of the kinematics analysed, particularly those related to speed, hand aperture, joint angles and compensation. Consequently, it is necessary to consider its influence in future studies.

In everyday life, ULs can be used in ADLs with different sensory-motor requirements (Raine, Meadows, & Lynch-Ellerington, 2009). Therefore, although the drinking task is extremely rich in different motor skills, it is necessary to study other ADLs to ensure maximum understanding of the UL motor control. It is also important that the selected tasks have different degrees of difficulty, especially when studying individuals with movement system dysfunction like poststroke patients, so that those with a higher level of sensorimotor impairment and hand impairment may also be studied.

6. Conflict of Interest Statement

The Authors report no conflicts of interest.

Article IV – Comparison of upper limb kinematics in two activities of daily living with different handling requirements

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ABSTRACT

Introduction: Drinking (DRINK) has been one of the most selected activities of daily living (ADLs) for kinematic analysis of upper limb (UL), but the accomplishment of this task may become difficult in poststroke adults with hand impairment. Therefore, for the quality of motor performance of the ULs of these patients may also be assessed, it is necessary to study ADLs in which the hand's role is easier. The main goal of this article was to compare the kinematic strategies used by healthy adults in an ADL with less demanding handling with those that are used in DRINK. Methods: 63 adults, aged 30 to 69 years old, drank water and turned on the light, using both ULs separately, while seated. Movement of both tasks were captured by a 3D motion capture system. End-point and joint kinematics of reaching and returning phases were analysed. A multifactorial analysis of variance with repeated measures was applied on the kinematic metrics, using age, sex, body mass index and dominance as main factors. Results: Mean and peak velocities, index of curvature, shoulder flexion and elbow extension were lower in turning on the light (LIGHT) task, which suggests that the real hand trajectory was smaller in this task. In LIGHT task, reaching was less smooth and returning was smoother than DRINK task. Instant of peak velocity was similar in the two tasks. There was a minimal anterior trunk displacement in LIGHT, and a greater anterior trunk displacement in DRINK. Age and sex were the main factors exerting effect on some of the kinematics, especially in LIGHT task. Conclusion: DRINK and LIGHT tasks include reaching a target and returning to the starting position. However, the different target formats and the different interaction with them seem to be responsible for differences in speed profile, efficiency, smoothness, as well as joint angles and trunk displacement. LIGHT task is not usually performed in the sitting position, which may have affected the selection of the best motor program and, consequently, highlighted the differences in kinematic strategies used by particular sample groups. This comprehensive and comparative analysis of typical UL movement during the performance of ADLs with different handling requirements may be a reference for future studies with poststroke adults with different levels of hand impairment.

Key words: upper extremity; motor performance assessment; kinematic analysis; drinking; turning on the light

1. Introduction

Recently, the inclusion of kinematic analysis in poststroke recovery trials was recommended by Stroke Recovery and Rehabilitation Roundtable (SRRR) (Kwakkel et al., 2017), to improve the understanding about the mechanisms that drive motor recovery. Kinematic analysis allows to describe the underlying biomechanical characteristics of motor function deficits and, therefore, differentiate restitution from compensation (Kwakkel et al., 2017). This understanding may be what is missing to optimize the upper limb (UL) recovery, since 50% of the poststroke patients experience chronic sensorimotor dysfunction of the contralesional UL (Kwakkel et al., 2003). The knowledge of typical movement (performed by healthy adults) becomes essential to determine and understand motor deficits presented by poststroke adults.

Drinking has been one of the most selected activities of daily living (ADLs) for kinematic analysis of the UL (Mesquita, Pinheiro, et al., 2019), particularly in studies involving poststroke adults (Aprile et al., 2014; Kim et al., 2014; Murphy et al., 2018; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009). Selecting an ADL allows to increase the studies validity as it is defended by several authors (de los Reyes-Guzmán et al., 2014; Kim et al., 2014; Mesquita, Pinheiro, et al., 2019; Murphy et al., 2012; Murphy et al., 2011). However, the accomplishment of this particular task may become difficult or even impossible in poststroke adults with greater sensorimotor impairment (Mesquita, Pinheiro, et al., 2019). During pre-shaping for grasping a target, while poststroke adults with mild to moderate impairment may show an extensive opening of the fingers (Nowak et al., 2007), those with more severe impairment have problems to open the fingers accurately (Lang et al., 2005), which makes it difficult not only to grasp the object, but also its release. To ensure an independent performance of drinking task, some authors defined as inclusion criteria in their studies: to have sufficient residual hand aperture and grasping ability to be able to complete the task without assistance (Thies et al., 2009); or to have a score of 65/66 to 66/66 in the Fugl-Meyer Assessment for Upper Extremity (FMA-UE) (Kim et al., 2014), which corresponds to a null or near null sensorimotor impairment of the UL. Therefore, many subjects may have been excluded from the studies performed so far, which may be compromising the understanding of poststroke motor sequelae as well as the recovery process of patients with more severe sensorimotor impairment (Mesquita, Pinheiro, et al., 2019). Consequently, it is necessary to select other ADLs with less demanding handling that these subjects can accomplish.

Moreover, considering the great variety of objects with which the human being interacts every day, it is important to know the kinematic strategies used in other ADLs. Reaching movement, for example, is present in most of them and it is known that it varies according to the goals (e.g. grasping or pointing) and constraints (position, distance and dimension of the object, postural demands, etc.) of the task (Shumway-Cook & Woollacott, 2017). Nevertheless, it is necessary to explore which movement components vary according to specific constraints, to improve the clinical reasoning underlying the evaluation and intervention performed in poststroke adults.

Therefore, the main objective of this study was to compare the kinematic strategies used by the ULs of healthy adults in an ADL with less demanding handling (turning on the light) with those that are used in drinking, through the analysis of end-point kinematics and joint kinematics. Unlike the drinking task, turning on the light involves reaching and touching a target (switch) without having to grasp it, transport it or release it. To our knowledge, no one else analysed this ADL or other ADL with similar components in healthy or poststroke adults. It was defined as secondary objective, to study if these kinematic strategies are significantly different between dominant and non-dominant UL, as well as between subjects with different age, sex and body mass index (BMI), since evidence (AlAbdulwahab & Kachanathu, 2016; Fradet et al., 2008; Morgan et al., 1994; Nakatake et al., 2017; Pohl et al., 1996; Solodkin et al., 2001; Vrtunski & Patterson, 1985; Welford, 1982; Williams, 1990) shows that these factors are responsible for differences in postural control, mobility skills or in the functional organization of motor areas.

2. Methods

2.1. Study design and participants

A cross-sectional observational study was carried out in a laboratory setting, after approval by the Ethics Committee of Faculty of Sports of University of Porto (CEFADE 08.2016). Though by responding to the online questionnaire subjects' consent was automatically considered, an additional written informed consent was obtained from all participants, according to the Helsinki Declaration.

Sample was recruited from a population of students, teaching and non-teaching staff from local higher education institutions, contacted through e-mail. On this email, people were informed about the study and invited to participate by fulfilling a characterization and inclusion/exclusion criteria selection questionnaire. From the two hundred and seventeen subjects that answered the questionnaire, sixty-three fit the criteria and were recruited. Subjects were included if they were ≥30 years old, had a BMI between 18.5 and 30.0, were right-handed (Murphy et al., 2006; Murphy et al., 2011), and had an insufficient physical activity level, i.e. not achieving 150 minutes of moderate-to-vigorous-intensity physical activity per week or 75 minutes of vigorous-intensity physical activity per week or an equivalent combination of moderate- and vigorous-intensity activity (Tremblay et al., 2017). The existence of musculoskeletal or neurological conditions which might affected the UL function, previous history of UL pathology or surgery and pain in this segment, and pregnancy were considered exclusion criteria. Table 1 presents the sample's demographic and anthropometric characteristics.

Table 1 - Demographic and anthropometric characteristics of the sample.

Characteristics, n=63	*Mean ± SD (Min-Max) or n (%)*
Age (years)*	46.8 ± 11.7 (30.0-69.0)
Age category‡	45 (71%) 30-55 years old, 18 (29%) 56-74 years old
Sex‡	25 (40%) Male, 38 (60%) Female
Height (m)*	1.63 ± 0.11 (1.37-1.84)
Weight (kg)*	66.88 ± 11.28 (49.00-100.00)
Length of the right upper limb (cm)*	56.63 ± 3.87 (48.50-66.50)
Length of the left upper limb (cm)*	56.61 ± 3.91 (48.50-66.50)
Body Mass Index*	25.05 ± 2.72 (19.70-29.90)
Body Mass Index Category ‡	29 (46%) Normal, 34 (54%) Overweight

*Mean, standard deviation, minimum and maximum values for continuous variables; ‡ n (%) for categorical variables

2.2. Motion capture system and marker setup

Tasks' movement was captured using eleven Oqus Qualisys cameras (Qualisys AB, Gotenburg, Sweden) operating at a sampling frequency of 200 Hz. Prior to each session the cameras were calibrated with a measurement volume of approximately 8 m^3 and a maximum acceptable error of 0.8 mm. A twenty-five reflective marker setup was used to create an upper body biomechanical model comprising both ULs, trunk and pelvis, according to a previous study (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019).

2.3. Experimental setup and procedures

The signal from the Turning on the light (LIGHT) and drinking (DRINK) tasks were performed in a seated position on a hydraulic gurney, whose height was adjusted to 100% of the leg length of each subject (figure 1) (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). The base of support and the location of the table and the targets were also normalized according to a previous study (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). To light the lamp, participants had to press a switch integrated into a vertical board. The square switch had an area equal to 42.25 cm^2 (6.5 x 6.5 cm). The switch of the lamp and the drinking glass had exactly the same position: at a distance of ipsilateral hip equal to length between the acromion and the trapezius-metacarpal joint of ipsilateral UL, in the sagittal plane (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). To ensure that the participants placed the glass in the same place from where they lifted it, a small round base was placed on the location determined for the glass. The drinking glass had 7.0 cm in diameter and 9.5 cm of height (volume 240 mL) and was filled with 120 mL of water (half-full) (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Murphy et al., 2006; Murphy et al., 2011).

The tasks were performed with both ULs separately. The order of tasks performance, as well as the beginner UL was randomly defined. Participants practiced the tasks a few times before registering. Prior to data collection, a static file was registered for later construction of the anatomical model in Visual3D software (C-Motion, Inc., Germantown, USA). Then, participants were instructed to, when hearing the command "you can drink" or "you can turn on the light", take a sip of water or turn on the light, respectively, at a comfortable self-paced speed (Aizawa et al., 2010; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009). Three trials were performed for each UL in the two tasks, with a break of one minute before each trial. After the tasks performance, participants were instructed to remain stable for 3 seconds (Aizawa et al., 2010), while looking steadily at the target.

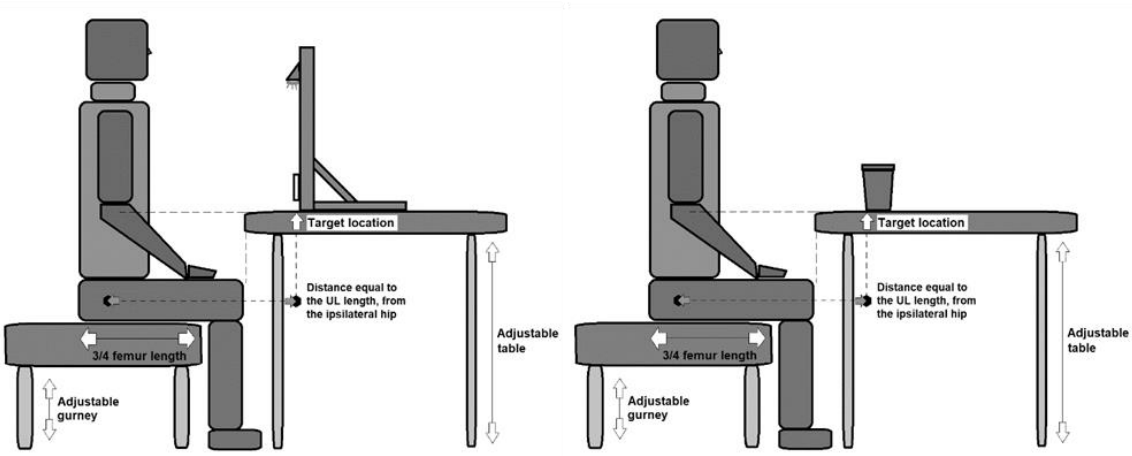


Figure 1. Experimental setup of turning on the light (left) and drinking (right) tasks.

Abbreviation: UL – upper limb.

2.4. Data processing and analysis

After the recording phase, the Qualisys Track Manager (Qualisys AB, Gotenburg, Sweden) software was used to identify each marker trajectory and to review if it was tracked correctly throughout the data capture. Trajectory gaps were interpolated using the built-in polynomial calculations, and the resulting data was exported to the Visual3D software (C-Motion, Inc., Germantown, USA) for further analysis. This software was used to build a biomechanical upper body model through the markers (according to appropriate C-motion recommendations (C-Motion, 2017)), to filter the movement trajectory data with a 6 Hz low-pass Butterworth filter, and to perform all the event detections and the metric calculations. A global and local coordinate system (for each segment) has been defined in which the X axis corresponded to the lateral (+) and medial (-) directions, the Y axis corresponds to the anterior (+) and posterior (-) directions, and the Z axis corresponds to the cephalic (+) and caudal (-) directions (Kim et al., 2014). Joint angles were calculated using the rotation order of the distal segment with respect to the proximal segment, applying each segment's local coordinate system (Kim et al., 2014).

DRINK task was, according to the literature (Kim et al., 2014; Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011), broken down into five phases: (a) reaching out for the glass from starting position, (b) transporting the glass forward to the mouth, (c) taking a drink (one sip), (d) transporting the glass backward to the pickup point, and (e) returning the hand to the initial position. However, in this article, we only included the analysis of the reaching and the returning phases. The LIGHT task was broken down into two phases (figure 2): (a) reaching out for the switch from starting position, and (b) returning the hand to the initial position. Start of the reaching phase of both tasks was defined as the time when the tangential velocity of the hand exceeded 2% of the maximum velocity in this phase (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011). End of the reaching phase of DRINK task was defined as the time when the tangential velocity of the hand exceeded 0.15 m/s after grasping the glass. Start of the returning phase of both tasks was detected when the linear hand velocity crossed the zero value downwards in the antero-posterior direction. End of the returning phase of both tasks was detected when the linear velocity of the hand crossed the zero value upwards in the anterior-posterior direction (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019).

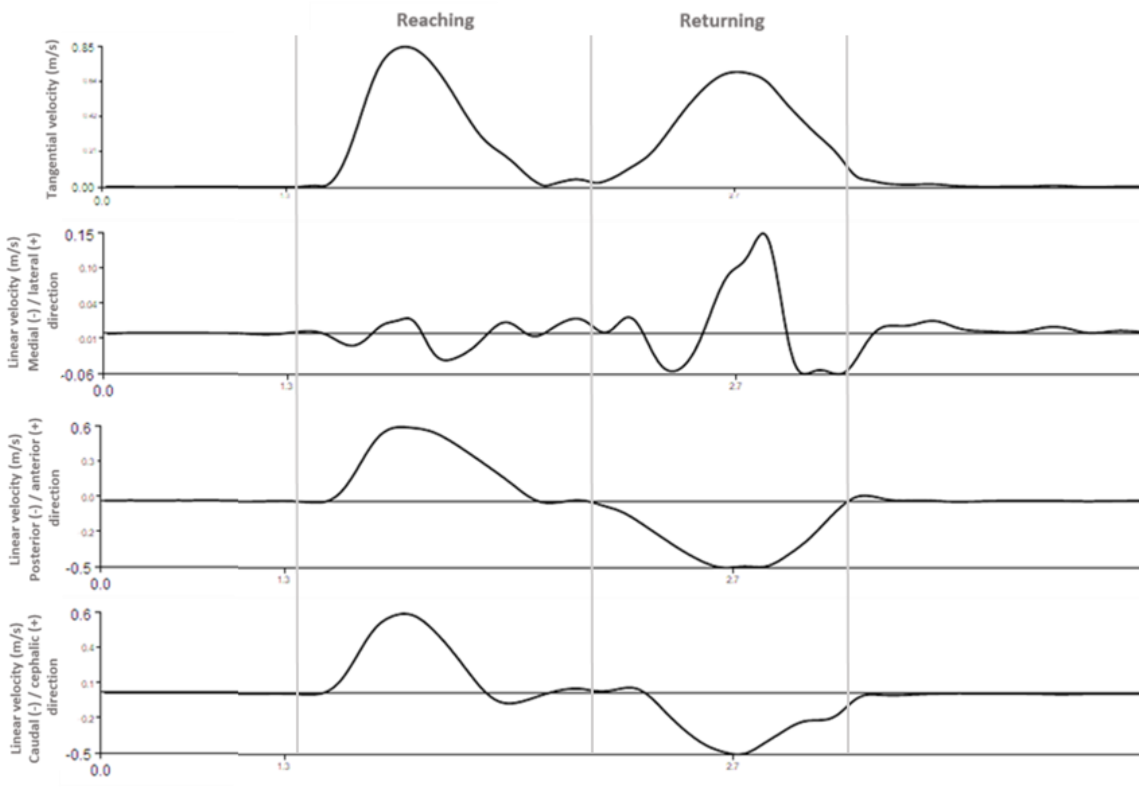


Figure 2. An example of phases definition of turning on the light task through hand's tangential velocity and hand's linear velocity in medial (-) / lateral (+), posterior (-) / anterior (+) and caudal (-) / cephalic (+) directions. The grey vertical lines are the event lines dividing the phases of the turning on the light task.

Figure 3 represents the kinematic metrics analysed for each phase and the component of movement they characterize, according to the study of de los Reyes-Guzmán et al. (2014):

- **Absolute duration**;
- **Mean velocities** and **peak velocities** were determined from tangential velocity of the hand;
- **Relative instant of peak velocity** was calculated from tangential velocity of the hand. This variable allows to measure the acceleration and deceleration periods, i.e., the control strategy used during the movement (de los Reyes-Guzmán et al., 2014);

- **Index of curvature** was determined through the calculation of the ratio of the path length and the line-of-sight distance between the initial to the final endpoint position. Values closed to 1.0 are representative of shorter hand trajectory during movement, i.e. an efficient movement (de los Reyes-Guzmán et al., 2014);

- **Number of movement units** (velocity peaks) was calculated, with a movement unit considered as the difference between a minimum and next maximum velocity value (of the tangential velocity profile of the hand) that exceeds the amplitude limit of 0.02 m/s. The time between 2 subsequent peaks had to be at least 0.15 seconds. A custom analysis routine was developed in Matlab R2014a (The MathWorks Inc. Massachussets, USA) for this calculations. A smoother movement has only one peak in the velocity profile of the hand movement (de los Reyes-Guzmán et al., 2014);

- **Joint angle in phase transition** of shoulder flexion (+) / extension (-), shoulder adduction (+) / abduction (-), shoulder medial rotation (+) / lateral rotation (-), elbow flexion (+) / extension (-), elbow pronation (+) / supination (-), wrist flexion (+) / extension (-), and wrist ulnar deviation (+) / radial deviation (-);

- **Trunk displacement** was determined through the difference between the end position of the trunk's center of mass at each phase, and its start position, in the sagittal, frontal and transverse planes. In sagittal plane, trunk displaced in anterior (+) and/or posterior (-) directions, in frontal plane trunk displaced in ipsilateral (+) and/or contralateral (-) directions, and in transverse plane trunk displaced in upwards (+) and/or downwards (-).

These kinematic metrics were calculated in all trials.

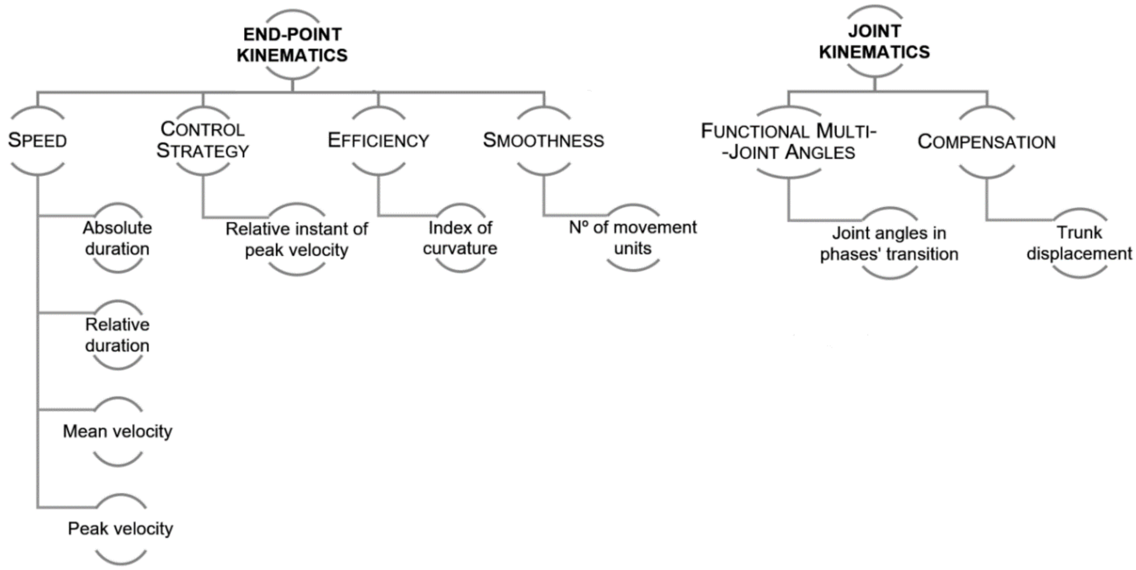


Figure 3. Metrics obtained from end-point and joint kinematic data and the characteristic of movement they represent, according to the de los Reyes-Guzmán et al. (2014).

2.5 Statistical analysis

Following the data processing, the statistical analysis was carried out using Statistica 13 software (TIBCO Software Inc, Palo Alto - CA, USA). The mean of the three trials of each participant was considered for statistical analysis. Outliers were identified using 2 standard deviation approach, and the values were replaced by central tendency. Descriptive statistics was performed using mean, standard deviation and frequency distribution. All the prerequisites for analysis of variance were met (normality, homogeneity and sphericity). A multifactorial analysis of variance with repeated measures was used, having as main factors: age category (30-55 years old, 56-74 years old, according to SRRR's recommendations (Kwakkel et al., 2017)), sex (female, male), BMI category (normal, overweight) and dominance (dominant UL, non-dominant UL). Interaction effects were identified by a Fisher post-hoc test and the effect sizes through the partial η^2, according to Cohen's guidelines (0.01=small; 0.06=medium; and 0.14=large effect) (Pallant, 2007). To avoid the possibility of inferring the existence of differences that do not really exist (type one error), we only considered relevant to report those that were associated with medium or large effect sizes. A significance level of 0.05 was used for all tests.

3. Results

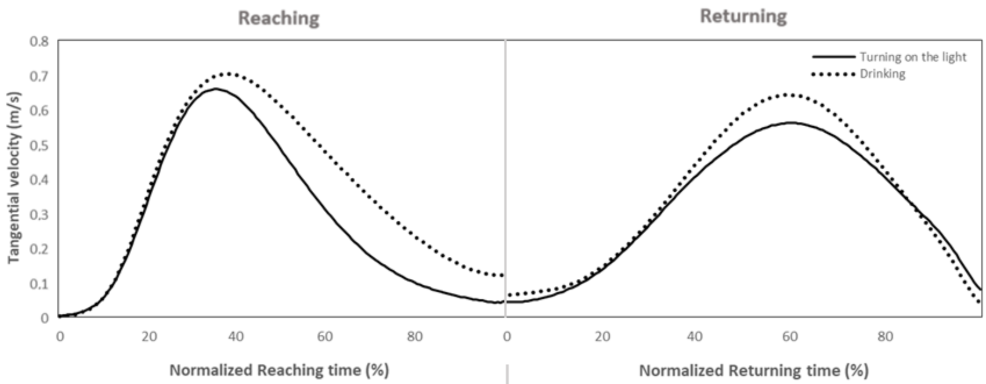
The normalized tangential velocity profile of hand and the normalized time histories of the joint angles are displayed in the figures 4 and 5, respectively. Below figure 4 are the respective kinematics with the exerted effects presented. Tables 2 and 3 present shoulder, elbow and wrist angles at the end of reaching of LIGHT and DRINK tasks, as well as trunk displacement in sagittal, frontal and transverse planes, during reaching and returning phases of both tasks, respectively. Kinematic values refer to the mean and standard deviation of the total sample (dominant and non-dominant ULs) or of sample groups in the kinematic metrics in which were found statistically significant differences with medium or large effects. Statistical values presented (p, F and ηp^2) refer to the analysis of variance with repeated measures, where the bold ones were those corresponding to statistically significant differences with medium or large effect.

3.1 End-point kinematics

3.1.1 Speed

Statistically significant differences between LIGHT and DRINK tasks were found in almost all kinematic variables that characterize speed, except in the absolute duration of reaching phase. In DRINK task, the absolute duration of returning phase and the mean and the peak velocities of both phases were higher than those of the LIGHT task.

No main factor exerted effect on the analysed phases of DRINK task. However, in the LIGHT task, age exerted effect on absolute duration and on peak velocity of reaching phase. Older adults (56-74 years old) took a longer time ($p<0.01$; $F(1,110)=9.30$; partial $\eta^2=0.08$) and had a lower peak velocity ($p<0.01$; $F(1,110)=11.67$; partial $\eta^2=0.10$) than younger adults (30-55 years old). Sex also exerted effect on this last variable, with women having a higher peak velocity than men ($p<0.01$; $F(1,110)=10.31$; partial $\eta^2=0.09$).



		Reaching		Returning	
Absolute duration (s)	LIGHT	30-55 y. old: 1.278 ± 0.248	p=0.42; F(1,110)=0.66; $\eta p^2<0.01$	0.973 ± 0.228	**p<0.01; F(1,110)=20.54; $\eta p^2=0.16$**
		56-74 y. old: 1.476 ± 0.398			
	DRINK	1.342 ± 0.269		1.095 ± 0.226	
Mean velocity (m/s)	LIGHT	0.230 ± 0.053	**p<0.01; F(1,110)=138.07; $\eta p^2=0.56$**	0.306 ± 0.070	**p<0.01; F(1,110)=53.79; $\eta p^2=0.33$**
	DRINK	0.289 ± 0.056		0.354 ± 0.070	
Peak velocity (m/s)	LIGHT	F: 30-55 y. old: 0.705 ± 0.118	**p<0.01; F(1,110)=71.66; $\eta p^2=0.39$**	0.575 ± 0.130	**p<0.01; F(1,110)=209.43; $\eta p^2=0.66$**
		F: 56-74 y. old: 0.621 ± 0.102			
		M: 30-55 y. old: 0.642 ± 0.087			
		M: 56-74 y. old: 0.542 ± 0.073			
	DRINK	0.744 ± 0.140		0.744 ± 0.135	
Relative instant of Peak velocity (%)	LIGHT	30.8 ± 5.6	p=0.01; F(1,110)=6.70; $\eta p^2<0.06$	F: Normal BMI: 50.5 ± 6.6	p=0.08; F(1,110)=3.19; $\eta p^2=0.03$
				F: Overweight: 55.6 ± 9.5	
				M: Normal BMI: 55.3 ± 9.8	
				M: Overweight: 60.6 ± 9.8	
	DRINK	32.5 ± 5.3		52.2 ± 10.4	
Index of curvature	LIGHT	F: 1.182 ± 0.090	**p<0.01; F(1,110)=101.74; $\eta p^2=0.48$**	F: 1.131 ± 0.078	**p<0.01; F(1,110)=157.82; $\eta p^2=0.59$**
		M: 1.258 ± 0.119		M: 1.173 ± 0.091	
	DRINK	1.340 ± 0.134		1.299 ± 0.119	
Number of movement units	LIGHT	30-55 y. old: 1.3 ± 0.3	**p<0.01; F(1,110)=30.76; $\eta p^2=0.22$**	30-55 y. old: 1.2 ± 0.3	**p<0.01; F(1,110)=10.15; $\eta p^2=0.08$**
		56-74 y. old: 1.7 ± 0.5		56-74 y. old: 1.5 ± 0.6	
	DRINK	1.2 ± 0.3		1.5 ± 0.4	

Figure 4. Normalized time history of hand's tangential velocity and end-point kinematics. Kinematic values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of sample groups in which were found statistically significant differences with medium or large effects. Statistical values presented (p, F and ηp^2) refer to the analysis of variance with repeated measures, where the bold ones were those corresponding to statistically significant differences with medium or large effect.Grey vertical line separates the two phases. BMI: Body Mass Index; F: Female; M: Male; y. old: years old.

3.1.2 Control strategy

In reaching phase, the peak velocity tended to occur earlier in the LIGHT task, but the effect size was small.

In returning phase, statistically significant differences between the two tasks were found just among men. Men had a later peak velocity in LIGHT task, comparatively to the DRINK task (p<0.01; F(1,110)=9.53; partial η^2=0.08).

Again, no factor exerted effect on DRINK task. On the other hand, BMI and sex exerted effect on returning phase of LIGHT task. Overweight participants and men had a later peak velocity, when compared with participants with normal BMI ($p<0.01$; $F(1.110)=14.72$; partial $\eta^2=0.12$) and women ($p<0.01$; $F(1,110)=11.73$; partial $\eta^2=0.10$), respectively.

3.1.3 Efficiency

LIGHT had a lower index of curvature than DRINK, in reaching and returning ($p<0.01$; $F(1,110)=157.82$; partial $\eta^2=0.59$) phases.

No factor exerted effect on DRINK task. Sex exerted effect on LIGHT. Women had a lower index of curvature than men in reaching ($p<0.01$; $F(1,110)=17.29$; partial $\eta^2=0.14$) and returning ($p<0.01$; $F(1,110)=8.52$; partial $\eta^2=0.07$) phases.

3.1.4 Smoothness

In LIGHT task, reaching was less smooth than that of DRINK. In turn, the returning phase of DRINK was less smooth than that of LIGHT.

No factor exerted effect on DRINK task. Age exerted effect on LIGHT task, with the older adults presenting a less smooth reaching ($p<0.01$; $F(1,110)=29.93$; partial $\eta^2=0.21$) and returning ($p<0.01$; $F(1,110)=9.94$; partial $\eta^2=0.08$) than younger ones.

3.2 Joint kinematics

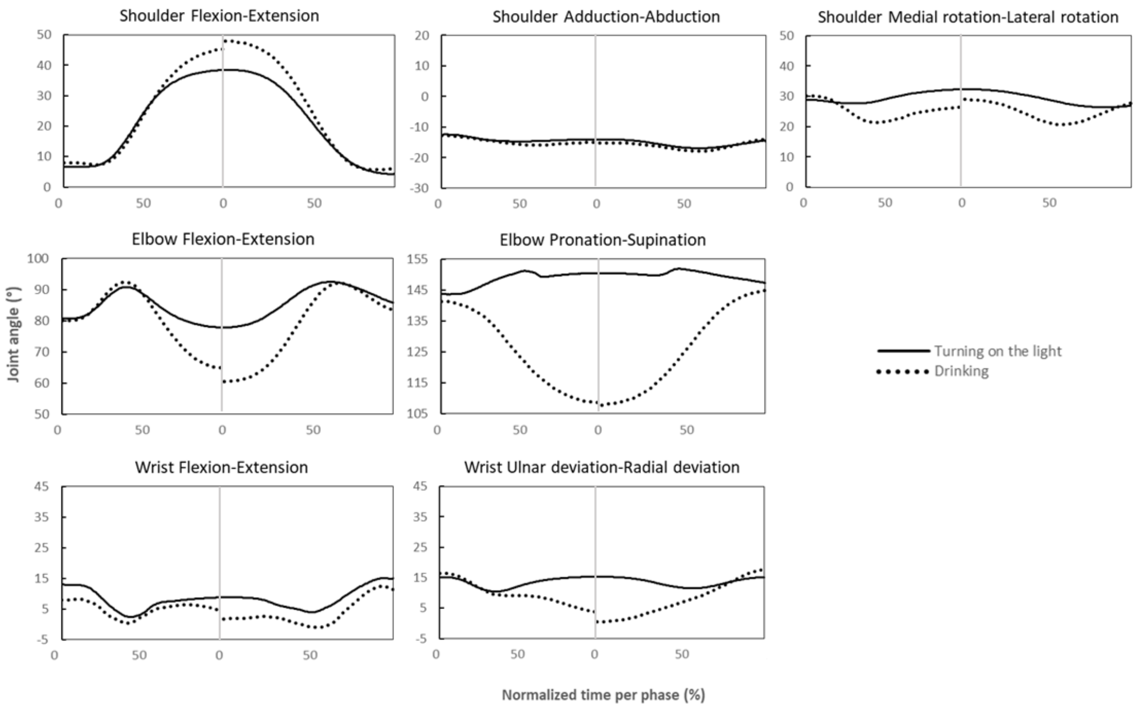


Figure 5. Normalized time history of shoulder, elbow and wrist angles during turning on the light and drinking tasks. Grey vertical lines are the event lines that separate reaching phase from returning phase.

3.2.1 Shoulder angles

At the end of the reaching of the respective targets, the degree of shoulder flexion was significantly lower in LIGHT than in DRINK task. In LIGHT task, the younger adults presented lower shoulder flexion than the older ones ($p<0.01$; $F(1,110)=9.27$; partial $\eta^2=0.08$).

In the frontal plane, there were no statistically significant differences between the two tasks. However, it should be noted that the dominant limb finished both tasks with a greater degree of shoulder abduction than the non-dominant limb (LIGHT: $p<0.01$; $F(1,110)=12.90$; partial $\eta^2=0.10$; and DRINK: $p<0.01$; $F(1,110)=9.15$; partial $\eta^2=0.08$). In addition, BMI also exerted effect in this LIGHT phase. Overweight adults completed reaching with a higher degree of shoulder abduction than those with normal BMI ($p<0.01$; $F(1,110)=19.84$; partial $\eta^2=0.15$).

In the transverse plane, the degree of shoulder medial rotation was greater in LIGHT than in DRINK.

Table 2 - Shoulder, elbow and wrist angles at the end of reaching of turning on the light and drinking tasks.

Joint angles	*Task*	*Joint angle at the end of reaching*		*Statistical values*
Shoulder Flexion-Extension angle (°)	LIGHT	30-55 y. old: 37.6 ± 5.8		**p<0.01; F(1.110)=216.04; ηp²=0.66**
		56-74 y. old: 41.0 ± 6.9		
	DRINK	46.5 ± 6.3		
Shoulder Adduction-Abduction angle (°)	LIGHT	Normal BMI	D limb: -13.3 ± 4.8	p=0.25; F(1.110)=1.35; ηp²=0.01
			ND limb: -10.9 ± 6.2	
		Overweight	D limb: -17.7 ± 5.5	
			ND limb: -14.4 ± 4.9	
	DRINK	D limb: -16.1 ± 5.2		
		ND limb: -13.3 ± 5.9		
Shoulder Medial rotation-Lateral rotation angle (°)	LIGHT	32.3 ± 7.7		**p<0.01; F(1.110)=13.15; ηp²=0.11**
	DRINK	26.8 ± 7.5		
Elbow Flexion-Extension angle (°)	LIGHT	Normal BMI: 74.2 ± 9.1		**p<0.01; F(1.110)=340.03; ηp²=0.78**
		Overweight: 80.6 ± 9.2		
	DRINK	F: 65.9 ± 9.3		
		M: 57.7 ± 8.6		
Elbow Pronation-Supination angle (°)	LIGHT	30-55 y. old: 155.6 ± 9.4		**p<0.01; F(1.110)=1223.40; ηp²=0.92**
		56-74 y. old: 150.2 ± 11.3		
	DRINK	30-55 y. old: 109.5 ± 10.9		
		56-74 y. old: 101.2 ± 11.5		
Wrist Flexion-Extension angle (°)	LIGHT	8.4 ± 9.3		**p<0.01; F(1.110)=24.69; ηp²=0.18**
	DRINK	F: 4.1 ± 7.1		
		M: 0.1 ± 7.9		
Wrist Ulnar deviation-Radial deviation angle (°)	LIGHT	15.6 ± 5.3		**p<0.01; F(1.110)=462.36; ηp²=0.81**
	DRINK	2.1 ± 5.4		

Kinematic values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of sample groups in which were found statistically significant differences with medium or large effects. Statistical values with significant differences with medium or large effect size are shown in bold. BMI: Body Mass Index; D: Dominant; F: Female; M: Male; ND: Non-dominant; y. old: years old.

3.2.2 Elbow angles

The degree of forearm pronation was markedly greater in LIGHT than in DRINK. Older adults presented a lower degree of forearm pronation in both tasks (LIGHT: $p<0.01$; $F(1,110)=12.19$; partial $\eta^2=0.10$; and DRINK: $p<0.01$; $F(1,110)=9.26$; partial $\eta^2=0.08$).

Elbow flexion was lower in DRINK than in LIGHT. In LIGHT, overweight adults have finished reaching with more elbow flexion ($p<0.01$; $F(1,110)=20.60$; partial

η^2=0.16). In DRINK, women finished reaching with more elbow flexion than men ($p<0.01$; $F(1,110)=11.01$; partial η^2=0.09).

3.2.3 Wrist angles

The degree of wrist ulnar deviation was markedly greater in LIGHT than in DRINK. Wrist flexion was also greater in LIGHT than in DRINK. Women presented greater wrist flexion than men ($p<0.01$; $F(1,110)=17.14$; partial η^2=0.13) in the latter.

3.2.4 Trunk displacement

Table 3 - Trunk displacement (m) in sagittal, frontal and transverse planes, during reaching and returning phases of turning on the light and drinking tasks.

Planes	*Task*	*Reaching phase*		*Returning phase*	
		Mean ± SD	*p value; ηp²*	*Mean ± SD*	*p value; ηp²*
Sagittal	LIGHT	0.001 ± 0.004	**$p<0.01$; ηp^2=0.49**	0.000 ± 0.003	**$p<0.01$; η^2=0.38**
	DRINK	0.013 ± 0.011		-0.008 ± 0.009	
Frontal	LIGHT	-0.001 ± 0.002	**$p<0.01$; ηp^2=0.39**	0.000 ± 0.002	**$p<0.01$; ηp^2=0.27**
	DRINK	30-55 y. old: 0.001 ± 0.004 56-74 y. old: 0.004 ± 0.004		-0.002 ± 0.004	
Transverse	LIGHT	0.001 ± 0.002	**$p<0.01$; ηp^2=0.10**	-0.002 ± 0.001	**$p=0.02$; ηp^2=0.08**
	DRINK	30-55 y. old: 0.001 ± 0.002 56-74 y. old: 0.003 ± 0.002		-0.002 ± 0.002	

Kinematic values refer to the mean and standard deviation of the total sample (dominant and non-dominant limbs) or of sample groups in which were found statistically significant differences with medium or large effects. Statistical values with significant differences with medium or large effect size are shown in bold. y. old: years old.

In LIGHT task, trunk displacement was significant lower than in DRINK in both phases and all planes, but especially in the sagittal and frontal ones. During reaching, it is noteworthy that the direction of trunk displacement was different in both tasks. In LIGHT task, trunk displaced to the opposite side of the UL that is moving, and in the DRINK task the opposite happened. Even comparing DRINK to LIGHT task, in the transverse plane, the older adults displaced more their trunk upwards in the DRINK task ($p<0.01$; $F(1,110)=10.66$; partial η^2=0.09).

No factor had any effect on the LIGHT task. In DRINK, age exerted effect on the frontal and transverse plane. Older adults displaced their trunk further upward ($p<0.01$; $F(1,110)=8.66$; partial $\eta^2=0.07$) and ipsilateral ($p<0.01$; $F(1,110)=10.25$; partial $\eta^2=0.09$) to the UL that is moving, than younger adults.

4. Discussion

In this article, kinematic strategies used by the ULs of healthy adults in an ADL with less demanding handling (turning on the light) were compared with those that are used in drinking, through the analysis of end-point kinematics and joint kinematics. No other study about kinematic analysis of the ULs, as far as we know: a) analysed turning on the light task; b) studied an ADL with less demanding handling; c) compared two ADLs with different handling requirements; d) analysed this set of kinematics. In addition, no other study normalized the base of support and the targets location to the anthropometric characteristics of each participant. Therefore, the comparison of our data with other previous studies was limited but made whenever relevant.

In order to promote the inclusion of poststroke adults with hand impairment in future studies, we chose an ADL that involves a simple interaction with an object of daily life: turning on the light (LIGHT). To accomplish this task, participants pressed a switch with an area of contact of 42.25 cm^2, which becomes simpler than a task involving grasping an object. With the aim of understand if the kinematic strategies used in this task were different from those used by the most selected ADL to kinematically analyse the ULs (drinking), we compared the end-point and joint kinematics recorded on LIGHT with those of DRINK. Although the interaction with the target is clearly different, these two tasks have two common gestures, which makes them comparable: i) reaching an object and ii) returning to the starting position. To ensure a comparison without interference of factors such as the distance and the height of the target, the location of the switch and the glass was exactly the same and was normalized to the anthropometric characteristics of each participant.

As the two analysed phases present different kinematic strategies, we chose to discuss their main characteristics separately. Finally, the observed effects exerted by age, sex, BMI and UL dominance on studied kinematics are discussed in the final section.

4.1 Reaching

The absolute duration of reaching in both tasks was similar, although the mean and peak velocities were lower in LIGHT task. We expected that reaching the switch would be shorter and faster than reaching the glass, since the theoretical trajectory of the hand was the same in both tasks and that the interaction with the glass was more demanding. In the study of Marteniuk et al. (1987), if the subject was asked to grasp the target, the movement duration of reaching was much longer than if the subject was asked to point and hit the target (Marteniuk, Mackenzie, Jeannerod, Athenes, & Dugas, 1987). However, our results may mean that the real trajectory of the hand was smaller in LIGHT task. This hypothesis is confirmed by the index of curvature. This index was lower in the LIGHT task, which indicated a less traveled trajectory in this task compared to DRINK one. Another result that seems to suggest that the end-point trajectory was smaller in the LIGHT task was the lower shoulder flexion and the lower elbow extension at the end of reaching in the LIGHT task. The different target formats and the different interaction with them seem to be the main factors that explains the existence of trajectories with different lengths. The switch is a flat target whose interaction consists of being pressed without the hand exceeding its limit. The glass is a cylindrical object, whose interaction implies that the hand overtakes it laterally and then grasps it. The joint kinematics analysed seem to support this theory. In LIGHT task, the hand was carried upwards and forwards, pressing the switch in a prone position, with slight wrist flexion and ulnar deviation. In DRINK task, the hand was carried to a lateral position to the glass through a greater shoulder flexion and a greater elbow extension, combined with shoulder lateral rotation. To grasp the glass at the end of the reaching, the forearm and wrist were close to neutral position.

It was also possible to verify that the velocity with which the hand reached and grasped the glass was higher than the velocity with which the hand reached and pressed the switch, which made the mean velocity, and possibly the peak velocity, to be higher in the DRINK task. These data seem to indicate that one of the main factors that interfered with the hand velocity profile was the interaction with the object, namely the need to decrease or not the hand velocity to handle the object. In LIGHT task, the interaction with the object was short, ending when the light came on. In DRINK task, interaction with the glass continued after the glass was held as it was transported towards the mouth. Therefore, the velocity with which the hand reached and grasped the glass may have been higher in the DRINK task to transport the glass to the mouth.

The different interaction with the target may also be the source of the lower smoothness of reaching to turning on the light. To turn on the light, it was necessary to press the switch and overcome its inertia. Thus, it was possible to observe in some cases, especially in older adults, a second peak velocity when this inertia was overcomed and the lamp was switched on.

The instant of the highest peak velocity was similar in both tasks, although the peak velocity tended to occur earlier in the LIGHT task. In the study of Marteniuk et al. (1987), when preparing to grasp an object, the acceleration phase of reaching movement was much shorter than the deceleration phase, but if the subject was asked to hit the target with the index finger, the acceleration phase was longer than the deceleration phase, with the subject hitting the target at a relatively high velocity. Usually a longer deceleration period is attributed to a more demanding reaching goal (Shumway-Cook & Woollacott, 2017), so we expected that DRINK task had the peak velocity sooner than the LIGHT task. However, our results suggest that the distinct interaction with the different targets and the different length in hand trajectories do not interfere with the control strategy during reaching and returning. In an earlier study (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019) in which we analysed all phases of DRINK, we found that those at which the peak velocity occurred earlier were reaching and forward transporting phases, and those at which the peak velocity occurred later were backward transporting and returning phases. In DRINK task, control the ending of the trajectory in reaching and forward transporting phases seems to be more demanding than in backward transporting and returning phases. Actually, the stability of the respective targets position seems to be different between phases. The glass and the mouth are targets whose position can be changed easily if hand velocity is excessive, i.e. the glass may tip over and the mouth may change its position in space or be hurt. On the other hand, table and thigh are targets that will hardly change their position if hand reaches them with an excessive velocity. Thus, the present study and previous article (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019) seem to suggest that the duration of the acceleration and deceleration periods depends mainly on the stability of the target position.

Trunk displacement in the sagittal and frontal planes was clearly different between the two tasks. In sagittal plane, there was a minimal anterior displacement in LIGHT task, and a greater anterior displacement in DRINK one. Usually, in pathologic cases as stroke ones, anterior trunk displacement is interpreted as a compensatory strategy of the impairment of shoulder flexion and elbow extension, during reaching (Cirstea & Levin, 2000). However, trunk displacement is also frequent in reaching performed by healthy adults in which the target distance is greater than UL length (Levin et al., 2002). Although in the present study, the targets were placed at a distance smaller than the length of the UL to decrease the need to move the trunk and at the same distance, the real trajectory of the DRINK task exceeded that of the LIGHT one. This probably increased the anterior and lateral displacement of the trunk in DRINK task. However, the more complex interaction with the glass may also have contributed to increased trunk displacement, since control of posture and hand mobility would have been more demanding. The increased distance between hand and trunk requires a greater postural control in sagittal and frontal planes, which CNS probably tried to lessen through anterior and lateral trunk displacement. In addition, to optimize sensory-motor control of the hand as well as improved the perception of glass position through visual information, CNS may have approached the trunk of the glass. In the frontal plane, in the LIGHT task the trunk tended to move contralaterally to the moving UL, which is an expected response to maintain the center of gravity within the limits of postural stability (Hodges, Cresswell, Daggfeldt, & Thorstensson, 2000; Shumway-Cook & Woollacott, 2017) and is probably easier to achieve in this easier task. Future studies should include the analysis of the trunk angles in the different planes, for a better understanding of the trunk behavior throughout the task.

4.2 Returning

It was also expected that the trajectory of returning in LIGHT task was shorter than that of returning in DRINK task, and this was confirmed by the index of curvature. This index was smaller in LIGHT task. However, unlike the reaching phase, returning of LIGHT task was smoother than that of DRINK one. This may have resulted from an additional component present just in the returning of DRINK task: the hand aperture and the releasing of the glass. Thus, as we did not perform this analysis it is relevant that future studies realize if the hand aperture is associated with the presence of a first peak velocity of the returning phase in DRINK task.

Performing a task with greater precision generally requires a slower velocity. Unexpectedly, the mean and peak velocities were greater again in DRINK task. Apparently, this result does not make sense, but can be better understood if future studies analyse angular velocities of the shoulder, elbow, wrist and trunk in the both phases. Probably, the greatest displacement of the trunk and greater range of motion in the shoulder and elbow have increased the hand velocity. Furthermore, it is necessary to consider the possibility of the perception of the glass being better than the switch in the sitting position. In daily life, DRINK is often performed in the sitting position, but turning on the light with this particular switch is usually performed in standing position. Thus, the selected position may have favored DRINK performance, resulting in a higher hand velocity.

4.3 Effects of age, sex, upper limb dominance and body mass index

The analysed factors had a greater influence on LIGHT task. This may have resulted from the fact that this task is not usually performed in the sitting position.

This may make it difficult to determine the best motor program for its accomplishment. Consequently, this may have highlighted the differences in kinematic strategies used by particular sample groups.

Age was the factor with the greatest impact especially in end-point kinematics of reaching of LIGHT task. Older adults took longer time and had lower peak velocity than the younger ones in this task's phase. Different systems could contribute to the slowing with aging, namely: a) the sensory and perceptual systems, such as the visual system; b) central processing systems; c) motor systems, and d) arousal and motivational systems (Welford, 1982). The absence of influence on the DRINK task may be also explained by a better perception of the glass, as well as by a greater motivation and arousal for this task, by older adults. Aging consequences in the referred systems may also explain the lower smoothness observed in the both phases of LIGHT by older adults. Concerning joint kinematics, it was found that older adults showed higher shoulder flexion at the end of the reaching in LIGHT task than younger adults. This could be result of a smaller upward displacement of the trunk in this task. Therefore, in DRINK task, older adults may have presented a lower shoulder flexion because they executed a greater upward displacement of the trunk. In reaching of DRINK task, older adults used also more ipsilateral trunk displacement than younger ones. This is compatible with changes in postural control, namely slowing in onset latencies for postural responses and in the use of feedback and feedforward control (Shumway-Cook & Woollacott, 2017). However, this may also be a result of the initial position of the trunk being different in the two age groups and thus implying different displacements in reaching phase. Older adults had also a lower angle of forearm pronation than younger ones in both tasks, which may result of a decreased mobility in this group (Shumway-Cook & Woollacott, 2017) and could also suggest possible changes in hand orientation with aging. Future studies should explore these issues.

Sex was the second factor with the greatest impact on the studied variables, again especially in LIGHT task. Women had a higher peak velocity in reaching and an earlier peak velocity in returning, when compared with men. These may result from sex difference in proportion of lean tissue distributed in the upper body, which is higher in men (Miller et al., 1993). This can cause an increased inertia during both phases, which could result in a lower peak velocity in reaching and a longer acceleration period during returning in men. Women were also more efficient than men in both phases of LIGHT task. To our knowledge, no study has ever compared the motor control efficiency of men and women. This could result of distinct sensory-motor control, anthropometric characteristics and/ or cultural reasons, which should be explored in future studies. At the transition between the two phases of DRINK task, women had also a greater elbow and wrist flexion than men. A recent study (Nakatake et al., 2017) that looked at differences between sex during eating, also found that women presented higher maximum elbow flexion, when using a spoon and chopsticks. Again, it is important to explore the multiple factors that may explain these differences between the both sexes in future studies.

Instant of peak velocity in the returning of LIGHT task occurred later in overweight adults, which could be consequence of an increased inertia resulting from the greater weight of the UL. In the same task, shoulder abduction and elbow flexion of overweight adults was also greater at the end of reaching. This could result of changes in the position and movement of the scapula in the rib cage that have already been identified in overweight adults (Gupta et al., 2013), but whose relation to the alignment and movement of the other joints of UL has not yet been explored.

Shoulder abduction of the dominant UL was higher than the non-dominant UL in both tasks. However, although this was a statistically significant difference, it should be considered whether a difference of approximately 3° is clinically relevant, also considering that the dominance had no effect on any other variable studied.

5. Conclusion

In this paper, it was made a comparison of the kinematic strategies used by healthy adults in a more challenging ADL (drinking) with those of an ADL with less demanding handling (turning on the light). Both tasks include in their performance reaching a target and returning to the starting position. However, their different target formats and their different interaction seem to be responsible for differences in speed profile, efficiency, smoothness, as well as joint angles and trunk displacement: in LIGHT task, mean and peak velocities, index of curvature, shoulder flexion and elbow extension were lower than that of DRINK task, suggesting that the real hand trajectory was smaller in LIGHT task; in this task, reaching was also less smooth and returning was smoother than DRINK task; there was a minimal anterior trunk displacement in LIGHT, and a greater anterior trunk displacement in DRINK. In addition, it was found that age and sex had significant effects on some of the kinematics analysed, particularly in LIGHT task. This may have resulted from the fact that this ADL is not usually performed in the sitting position, which could affect the selection of the best motor program and, consequently, highlighted the differences in kinematic strategies used by particular sample groups.

The conclusions obtained allow a better understanding of the kinematic strategies used in two ADL with different handling requirements. This comprehensive and comparative analysis of typical movement may be a reference for future studies with poststroke adults with different levels of hand impairment.

6. Conflict of Interest Statement

The Authors report no conflicts of interest.

<u>Article V</u> – Kinematic analysis of both upper limbs after stroke: a case series

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Journal: (submitted)

ABSTRACT

Introdution: Kinematic analysis has been used widely to better understand contralesional upper limb (cUL) motor deficits and recovery after stroke. However, increasing evidence shows that motor impairment affects ipsilesional UL (iUL), a fact that has been largely ignored in previous studies. Moreover, some gaps in patients' stratification, in the selected motor tasks and in the kinematic metrics analyzed have been identified, which may compromise gathering and interpreting data. Therefore, the aim of this case series was to analyse the kinematic strategies of both ULs of poststroke adults in the early sub-acute phase (T1) and in the beginning of chronic phase (T2), through a new methodological approach. Methods: We included five stroke adults. Characterization of patients and their stroke was made according to recent recommendations of the Stroke Rehabilitation and Research Roundtable (SRRR). They performed two activities of daily living, namely drinking and/or turning on the light tasks with both ULs, separately, according to their hand impairment. Tasks movements were captured by a 3D motion capture system. End-point and joint kinematics were analysed, and compared to healthy adults (previously studied). Poststroke values beyond the confidence interval of healthy adults were considered kinematic alterations. Results: Substantial differences were found between the kinematic strategies used by stroke patients and healthy adults. All patients presented kinematic alterations in both ULs, in T1 and T2, although, in most cases, the alterations were more subtle in iUL and their extent have decreased from T1 to T2. Conclusion: To our knowledge, this was the first study to apply SRRR recommendations for patient and stroke information collection; to select two ADLs with different handling requirement; and to analyse a comprehensive set of end-point and joint kinematics bilaterally. Stroke patients showed significant kinematic alterations in both ULs, which supports the implementation of bilateral assessments to fully study motor impairment post stroke. However, the clarification of kinematic metrics interpretation and the identification of a core set of kinematics are still needed.

Keywords: contralesional upper limb; ipsilesional upper limb; motor performance quality assessment; drinking; turning on a light.

1. Introduction

Stroke is considered a major cause of disability worldwide (Albert & Kesselring, 2012; Peter Langhorne et al., 2009; Sacco et al., 2013). The most common and widely recognized impairment caused by stroke is motor impairment (Peter Langhorne et al., 2009). Motor impairment of contralesional upper limb (cUL) is particularly worrying as more than 80% of stroke survivors experience acute sensorimotor dysfunction of this limb (Cramer et al., 1997), which becomes chronic for 50% of the patients (Kwakkel et al., 2003). Although less studied and recognized, increasing number of studies (Bustren et al., 2017; Desrosiers et al., 1996; Metrot et al., 2013; Noskin et al., 2008; Nowak et al., 2007; Sunderland et al., 1999; Wetter et al., 2005) have reported deficits in ipsilesional upper limb (iUL) as well. However, it is controversial whether these ipsilesional deficits remain present in the chronic phase of stroke recovery. Upper limb (UL) dysfunction is responsible for limitation of activities (disability) and reduced participation (handicap) of survivors and their caregivers in everyday life situations (Peter Langhorne et al., 2009), which affects their quality of life (Godwin et al., 2013). Therefore, the recovery and the return to a full life following stroke become the main goals for stroke survivors, caregivers and health professionals (Peter Langhorne et al., 2009; Walker et al., 2017).

UL sensorimotor recovery seems to be particularly slower or more complex than that of the lower limb, which could result from the wide range of activities of daily living (ADL) performed by ULs, involving varied interactions with diverse objects and a complex multi-joint coordination (Levin et al., 2009). Several studies (Aizawa et al., 2010; Chen et al., 2010; Finley et al., 2012; Jacquier-Bret et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Andel et al., 2008; van Dokkum et al., 2014; Wagner et al., 2008) have been performed to better understand this motor complexity, as well as UL motor recovery after stroke, through kinematic analysis. Kinematic metrics are considered the best way to measure motor recovery, since they can differentiate restitution from compensation, providing objective and quantitative parameters (Kwakkel et al., 2017). However, some gaps have been identified in the used methods of these studies, namely in patients' stratification (Kwakkel et al., 2017; Mesquita, Pinheiro, et al., 2019), in the selected motor tasks (Mesquita, Pinheiro, et al., 2019) and in the kinematic variables analysed (Mesquita, Fonseca, Pinheiro, et al., 2019).

First, stroke research is often designed with a "one size fits all" point of view (Boyd et al., 2017), although the term "stroke" describes a very heterogeneous group of clinical conditions (Sacco et al., 2013). A recent systematic review (Mesquita, Pinheiro, et al., 2019) found that most of the articles between 2007 and 2017 did not collect most of the demographic and stroke information recommended by the Stroke Rehabilitation and Research Roundtable (SRRR) (Kwakkel et al., 2017) to optimize stratification. Initial stroke severity and stroke location, considered major determinants of stroke recovery (Albert & Kesselring, 2012; Nudo, 2013), were some of the missing information, which makes the results and conclusions of these studies vulnerable to patients heterogeneity (Bernhardt et al., 2016). Considering this heterogeneity, case series or case reports may be more useful in improving case characterization, data recording, and trend analysis of outcomes (Carey & Boden, 2003). Besides that, most of the articles analysed poststroke adults in the chronic phase, with a very variable evolution time (from 0.5 up to 14.5 years) (Mesquita, Pinheiro, et al., 2019), though SRRR recommended that, whenever possible, the first assessment to stroke recovery research should be done at least until three months after stroke (Kwakkel et al., 2017).

Regarding motor tasks, "drinking" was the most analysed task in studies with poststroke adults (Mesquita, Pinheiro, et al., 2019). Although the this task includes such everyday gestures as grasping, transporting and releasing objects, some authors (Murphy et al., 2018; Murphy et al., 2011) focused their analysis essentially on reaching, limiting the knowledge about the gestures. Moreover, drinking may become too difficult for patients with hand impairment, excluding them from analysis (Mesquita, Pinheiro, et al., 2019). Another problem identified was the non-adjustment of the experimental setup to the anthropometric characteristics of each individual, which may be affecting the kinematic outcomes (Mesquita, Pinheiro, et al., 2019).

Finally, according to another recent systematic review (Mesquita, Fonseca, Pinheiro, et al., 2019), diverse authors (Finley et al., 2012; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Ozturk et al., 2016; Patterson et al., 2011; Thies et al., 2009; van Dokkum et al., 2014; Wagner et al., 2008) studied different kinematic variables to analyse ULs, making it difficult to define a core set of kinematic measures. Certain authors only analysed “end-point kinematics” (Thies et al., 2009) or “joint kinematics” (Aizawa et al., 2010), while others (Murphy et al., 2013; Murphy et al., 2012) analysed these both sets, but selected only one or two metrics. Since it is not clear if the Central Nervous System (CNS) programs movement synergies exclusively by end-point coordinates or by joint angle coordinates (Shumway-Cook & Woollacott, 2017), it is important to make a comprehensive analysis that includes wider sets of kinematic metrics.

Therefore, to promote advances in this knowledge area, the main objective of this study was to analyse the kinematic strategies of both ULs of poststroke adults in the early sub-acute phase and in the beginning of the chronic phase, through a case series and with a methodological approach that includes: i) the characterization of patients and their stroke, recommended by SRRR (Kwakkel et al., 2017); ii) the selection of ADLs with different handling requirements; iii) the normalization of tasks environment to the anthropometric characteristics of each patient; and, iv) the bilateral analysis of "end-point kinematics" and "joint kinematics".

2. Methods

2.1 Study design and setting

This case series was conducted based on PROCESS guidelines for case series (Agha et al., 2018). It had a longitudinal observational design and was carried out in a laboratory setting. Patients were recruited from a population of poststroke adults from four local medical institutions: Centro Hospitalar Universitário São João, Centros Hospitalares of Porto and Vila Nova de Gaia/Espinho, and Unidade Local de Saúde de Matosinhos. Approval for this study was obtained from the Ethics Committees of the involved medical institutions and of the University of Porto. Patients were recruited from February 2017 until November 2017 and all eligible patients were screened by neurologists during the recruitment period. After discharge, eligible patients were assessed by one experienced neurologist physical therapist in a laboratory in two moments: in the early subacute phase (T1) - whenever possible at 30 days after stroke - and in the beginning of chronic phase, i.e. 6 months after stroke (T2). In these two moments, a kinematic analysis of both ULs was carried out. The data collection period run from April 2017 until May 2018.

2.2 Participants

Dedicated neurologists selected patients who met the inclusion criteria, namely: i) to have the first ever ischemic or hemorrhagic stroke (Murphy et al., 2013), unilateral, with less than one month of evolution; ii) to have sensorimotor impairment of cUL (<66 in Fugl-Meyer Assessment for Upper extremity (FMA-UE)); iii) to be ≥30 years old; and iv) to be right-handed (Murphy et al., 2006; Murphy et al., 2011). Patients were excluded if they had: i) severe sensorimotor impairment of cUL (<39 in FMA-UE); ii) other neurological, neuromuscular or orthopedic conditions affecting ULs and trunk (Finley et al., 2012; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Patterson et al., 2011); iii) pain in ULs and/or trunk (Wagner et al., 2008); iv) hemi-spatial neglect (van Dokkum et al., 2014), uncorrected visual changes (Thies et al., 2009) and/or cognitive deficits (van Dokkum et al., 2014; Wagner et al., 2008), which compromised the understanding and accomplishment of the experimental protocol. Sixty-two patients were selected, of which thirty-seven were excluded because they presented: other neurological, neuromuscular or orthopedic conditions affecting ULs and trunk (n=17); severe sensorimotor impairment of cUL (n=10); hemi-spatial neglect, uncorrected visual changes and/or cognitive deficits (n=9); and pain in ULs and/or trunk (n=1). Of the remaining twenty-five, two died and eighteen were unable to participate in the study because they were transferred to a rehabilitation unit, which made it impossible for them to carry out the evaluation in the laboratory. All participants provided written informed consent.

Table 1 shows the demographic and stroke information of the five patients included in this case series. The information collected by the neurologists and the physical therapist followed the SRRR recommendations (Kwakkel et al., 2017). In addition, anthropometric (height, weight and ULs length) and physical therapy data were also collected. All of them had an Iberian ethnicity, a premorbid function without changes (score 0 in Modified Rankin Scale), an independent premorbid walking status, and lived at home with their relatives before the stroke.

2.3 Motion capture system and marker setup

The ADLs movements were captured using eleven Oqus Qualisys cameras (Qualisys AB, Gotenburg, Sweden) operating at a sampling frequency of 200 Hz. Prior to each session the camera system was calibrated with a measurement volume of approximately 8 m^3 and a maximum acceptable error of 0.8 mm. A twenty-five reflective marker setup was used to create an upper body biomechanical model comprising both ULs, trunk and pelvis, according to previous studies (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019).

Table 1 - Demographic, anthropometric and stroke characteristics of the cases.

Characteristics	*Patient 1*	*Patient 2*	*Patient 3*	*Patient 4*	*Patient 5*
Age (years)	51	53	53	80	60
Sex	Male	Female	Male	Male	Male
Height (m)	1.67	1.62	1.72	1.64	1.80
Weight (kg)	T1: 74; T2: 71	T1 and T2: 66	T1 and T2: 77	T1: 90 ; T2: 93	T1: 59 ; T2: 64
Body Mass Index	T1: 26.5; T2: 25.5	25.1	26.0	T1: 33.5; T2: 34.6	T1: 18.2; T2: 19.8
Length of the ULs (cm)	iUL: 58.5; cUL: 59.0	57.0	60.0	61.0	iUL: 61.0; cUL: 62.0
Medical history	Diabetes. Hyperlipidemia. Smoking and Alcohol use. Hypertension	Prior transient ischaemic attack (TIA)	Hypertension. Hyperlipidemia. Alcohol Use	Diabetes. Hyperlipidemia. Hypertension and Clinical obesity	Hypertension and Smoking use
Education	9th grade	4th grade	4th grade	6th grade	6th grade
Stroke severity (NIHSS)	6 (moderate stroke)	4 (minor stroke)	13 (moderate stroke)	9 (moderate stroke)	9 (moderate stroke)
Active hand movement at stroke onset	Yes	Yes	Yes	Yes	Yes
Ability to walk independently at stroke onset	Yes	Yes	No	No	No
Stroke type	Ischaemic	Ischaemic	Haemorrhagic	Ischaemic	Ischaemic
Stroke sub-type	Large artery	Large artery	Parenchymal	Large artery	Large artery
Stroke side	Right	Left	Right	Right	Right
Stroke location	Cortical: Middle cerebral artery	Subcortical: Basal Ganglia. Internal Capsule and Corona Radiata	Pons and middle and superior cerebellar peduncles	Subcortical: Basal Ganglia and Internal Capsule	Postcentral gyrus (cortical) and Corona radiata (sub-cortical)
Thrombolysis/ reperfusion therapy	No	Yes	No	Yes	Yes
Time post stroke onset	T1: 26 days; T2: 6 months	T1: 26 days; T2: 6 months	T1: 43 days; T2: 6 months	T1: 36 days; T2: 6 months	T1: 30 days; T2: 6 months
Total of FMA-UE (sub-total of "Hand" section)	T1: 62 (14); T2: 61 (14)	T1: 65 (14); T2: 66 (14)	T1: 57 (13); T2: 60 (14)	T1: 46 (7); T2: 58 (14)	T1: 50 (13); T2: 62 (14)
Started physiotherapy before T1	No	No	Yes	Yes	Yes
Physiotherapy between T1 and T2	No	Yes	Yes	Yes	Yes
Finished physiotherapy between T1 and T2	-	Yes	No	No	No

Abbreviation: cm – centimeter; cUL: contralesional upper limb; FMA-UE – Fugl-Meyer Assessment for Upper Extremity; iUL: ipsilesional upper limb; kg –kilogram; m- meter; T1: early acute phase after stroke; T2: beginning of chronic phase after stroke; NIHSS – National Institutes of Health Stroke Scale.

2.4 Experimental setup and procedures

Selected ADLs were drinking a sip of water (DRINK) and turning on the light (LIGHT), previously analysed kinematically in healthy adults (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). All patients performed the LIGHT task with both ULs and the DRINK task with the iUL, while the DRINK task with the cUL was only performed by participants who scored above 7 in the "Hand" section of the FMA-UE.

LIGHT and DRINK tasks were performed in the same seated position of previous studies (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). The lamp and the drinking glass were placed on a table, whose height was adjusted to the olecranon's height of each patient (Kim et al., 2014; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). To light the lamp, participants had to press a switch integrated into a vertical board. The square switch had an area of 42.25 cm2 (6.5 x 6.5 cm). The switch and the glass had exactly the same position: at a distance of ipsilateral hip equal to the length between the acromion and the trapezius-metacarpal joint, in the sagittal plane (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). To ensure that the participants placed the glass in the same place from where they lifted it, a small round base was placed on the location determined for the glass. The glass had 7.0 cm in diameter and 9.5 cm of height (volume 240 mL) and was filled with 120 mL of water (half-full) (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Murphy et al., 2006; Murphy et al., 2011).

The tasks were performed with both ULs separately. The order of tasks performance, as well as the beginner UL was randomly defined. Participants practiced the tasks a few times before registering. Prior to data collection, a static file was registered for later construction of the anatomical model in Visual3D software (C-Motion, Inc., Germantown, USA). Then, participants were instructed to, when hearing the command "you can drink" or "you can turn on the light", take a sip of water or turn on the light, respectively, at a comfortable self-paced speed

(Aizawa et al., 2010; Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019; Murphy et al., 2006; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009). Three trials were performed for each UL in the two tasks, with a break of one minute between trials. After the tasks performance, participants were instructed to remain stable for 3 seconds (Aizawa et al., 2010), while looking steadily at the target.

2.5 Data processing and analysis

After the recording phase, the Qualisys Track Manager (Qualisys AB, Gotenburg, Sweden) software was used to identify each marker trajectory and to review if it was tracked correctly throughout the data capture. Trajectory gaps were interpolated using the built-in polynomial calculations, and the resulting data was exported to the Visual3D software (C-Motion, Inc., Germantown, USA) for further analysis. This software was used to build a biomechanical upper body model through the markers (according to appropriate C-motion recommendations (C-Motion, 2017)), to filter the movement trajectory data with a 6 Hz low-pass Butterworth filter, and to perform all the event detections and the metric calculations. A global and local coordinate system (for each segment) has been defined in which the X axis corresponded to the lateral (+) and medial (-) directions, the Y axis corresponds to the anterior (+) and posterior (-) directions, and the Z axis corresponds to the cephalic (+) and caudal (-) directions (Kim et al., 2014). Joint angles were calculated using the rotation order of the distal segment with respect to the proximal segment, applying each segment's local coordinate system (Kim et al., 2014).

DRINK task was, according to previous studies (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019), divided into five phases: (a) reaching out for the glass from starting position, (b) transporting the glass forward to the mouth, (c) taking a drink (one sip), (d) transporting the glass backward to the pickup point, and (e) returning the hand to the initial position. LIGHT task was divided into two phases:

(a) reaching out for the switch from starting position, and (b) returning the hand to the initial position, according to Mesquita et al. study (2019b).

The kinematic metrics analysed were:

- **Absolute duration** and **relative duration**, calculated for each phase of the two tasks;

- **Mean velocities** and **peak velocities**, determined for each phase of the two tasks from tangential velocity of the hand;

- **Relative instant of peak velocity**, calculated for each phase of the two tasks (except drinking phase) from tangential velocity of the hand. This variable allows to measure the acceleration and deceleration periods, i.e., the control strategy used during the movement (de los Reyes-Guzmán et al., 2014);

- **Index of curvature**, determined for each phase of the two tasks (except drinking phase) through the calculation of the ratio of the path length and the line-of-sight distance between the initial to the final endpoint position. Values closed to 1.0 are representative of shorter hand trajectory during movement, i.e. an efficient movement (de los Reyes-Guzmán et al., 2014);

- **Number of movement units** (velocity peaks), calculated for each phase of the two tasks, with a movement unit considered as the difference between a minimum and next maximum velocity value (of the tangential velocity profile of the hand) that exceeds the amplitude limit of 0.02 m/s. The time between 2 subsequent peaks had to be at least 0.15 seconds. A custom analysis routine was developed in Matlab R2014a (The MathWorks Inc. Massachussets, USA) for this calculations. A smoother movement has only one peak in the velocity profile of the hand movement (de los Reyes-Guzmán et al., 2014);

- **Joint angle in each phase transition** of the two tasks shoulder flexion (+) / extension (-), shoulder adduction (+) / abduction (-), shoulder medial rotation (+) / lateral rotation (-), elbow flexion (+) / extension (-), elbow pronation (+) / supination (-), wrist flexion (+) / extension (-), and wrist ulnar deviation (+) / radial deviation (-);

- **Absolute maximum magnitude of hand aperture** (maximum distance between the thumb and index finger markers) (Patterson et al., 2011) and relative instant of maximum hand aperture during the reaching and returning phases of DRINK task. These variables allow to measure the pre-shaping strategy during the reaching phase of drinking task, and the release of the glass strategy during the returning phase;
- **Trunk displacement** was determined through the difference between the end position of the trunk's center of mass at each phase of two tasks, and its start position, in the sagittal, frontal and transverse planes. In sagittal plane, trunk displaced in anterior (+) and/or posterior (-) directions, in frontal plane trunk displaced in ipsilateral (+) and/or contralateral (-) directions, and in transverse plane trunk displaced in upwards (+) and/or downwards (-).

These kinematic metrics were calculated in all trials.

2.5 Statistical analysis

Following the data processing, the statistical analysis was carried out using Statistica 13 software (TIBCO Software Inc, Palo Alto - CA, USA). The mean of the three trials of each participant was considered for statistical analysis. Descriptive statistics was performed using mean, standard deviation and frequency distribution. Confidence intervals of 99% of the kinematic metrics of a healthy sample with a normal distribution (previously studied (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019) with the same methodology) were considered as the reference for detecting extreme values. Poststroke values beyond the confidence interval of kinematic metrics of healthy reference were considered kinematic alterations and highlighted in bold in table 2. Age and BMI categories of patient 4 did not fit in the available healthy sample categories. Therefore, for his kinematic metrics influenced by age and/or BMI factors, the reference values were those of age and BMI categories immediately below ("56-74" and "overweight", respectively).

3. Results

End-point and joint kinematics are presented in table 2. Description of main kinematic changes of each patient in T1 and T2 was made in the sections below and some of them are presented in figures 1-5.

3.1 Patient 1

In T1, patient 1 had several bilateral alterations in both tasks, according to the reference values, mainly in absolute duration, mean and peak velocities, magnitude of hand aperture and shoulder abduction, although most of them were more subtle in iUL. This patient performed most phases (except drinking) at a slower velocity, taking longer to accomplish them; both hands opened less, either to grasp or to release, opening later than expected during reaching; and both ULs also had excessive shoulder abduction values in the transition between almost all phases. Furthermore, both ULs had longer deceleration periods in reaching of DRINK and backward transporting and a lower efficiency in forward transporting. It is also noteworthy that cUL had a greater impairment of the smoothness in all phases and tasks evaluated, and presented wrist radial deviation rather than ulnar deviation in all phases transition.

In T2, some of the described alterations have improved, namely absolute duration of cUL and mean velocities, but others have got worse. Reaching the glass with cUL seems to have been particularly difficult at this moment, as the index of curvature increased, hand deceleration begun earlier and there was greater displacement of the trunk in anterior, ipsilateral and upward directions. In addition, the contralesional hand opened even less to grasp and release, taking longer to reach maximum aperture during returning. Excessive shoulder abduction worsened bilaterally and in almost every phase. Smoothness of returning, especially of LIGHT task has also worsened.

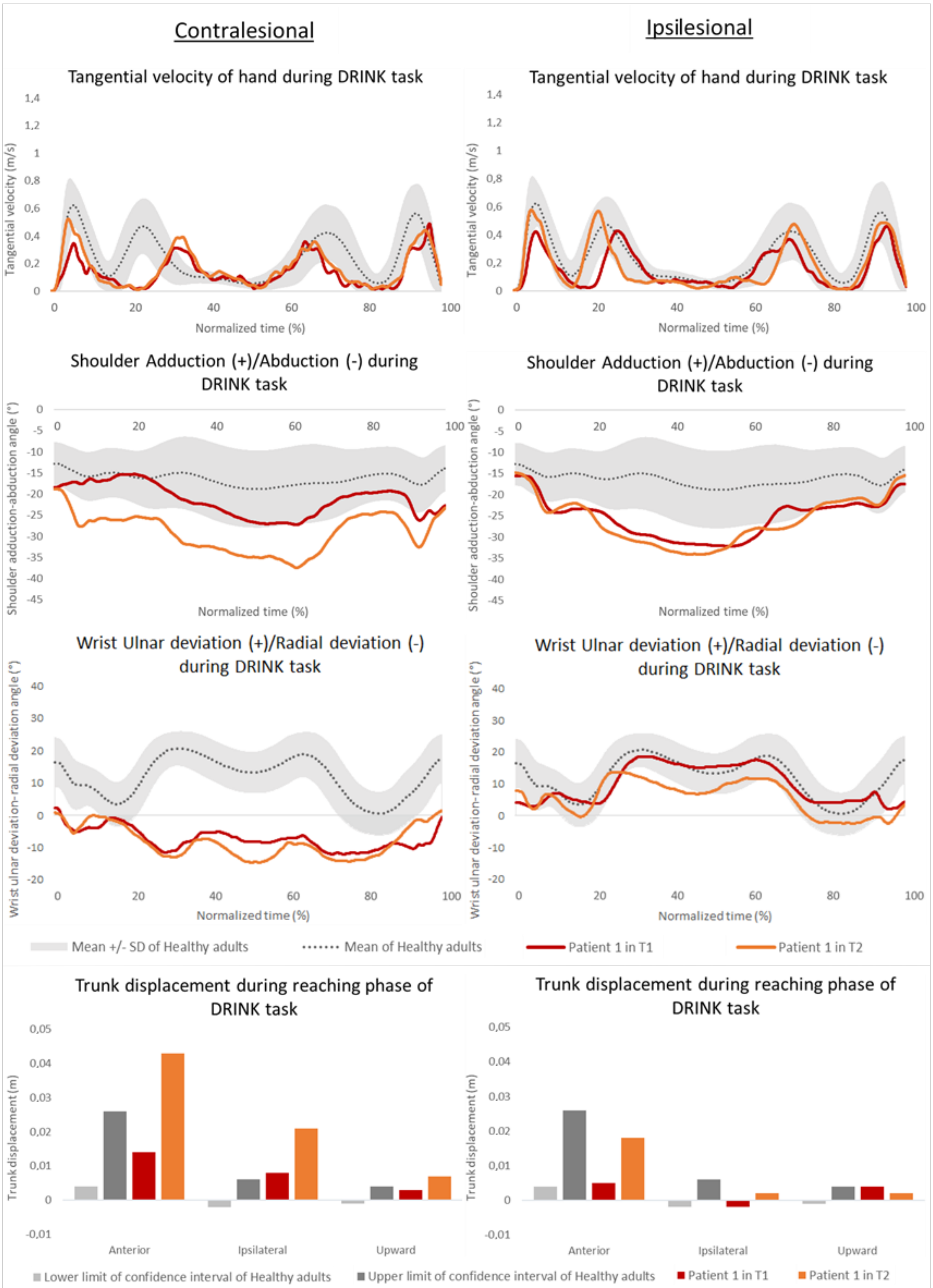

Figure 1. Some of the main kinematic alterations of Patient 1 in T1 and T2.

Table 2 - End-point and joint kinematics of both upper limbs of studied patients in T1 and T2 and the respective reference on the right. Kinematic values beyond the confidence interval of those healthy reference were considered kinematic alterations and highlighted in bold.

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		REFERENCE (confidence interval of 99%)
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Absolute duration (s)													
Reaching	LIGHT	C	**2.345**	**1.680**	**1.613**	1.505	**2.467**	1.207	**2.222**	1.638	1.897	**1.147**	30-55 y. old: [1.071 ; 1.584]
		I	**1.918**	**2.007**	1.262	1.495	**2.003**	1.412	**2.080**	1.395	**1.120**	1.277	56-74 y. old: [1.172 ; 2.045]
	DRINK	C	**3.205**	**3.112**	1.328	1.442	**3.750**	**2.228**	-	**2.292**	**2.698**	1.643	[1.113 ; 1.660]
		I	**2.220**	**1.685**	1.280	**1.078**	**2.198**	**1.965**	**1.920**	1.430	1.135	1.153	
Forward transporting	DRINK	C	**1.963**	**1.525**	1.388	**1.503**	**2.138**	**1.798**	-	**2.120**	**1.832**	1.445	30-55 y. old: [1.054 ; 1.490]
		I	**1.722**	**1.660**	**1.048**	1.125	**1.867**	1.343	1.697	1.368	1.690	1.355	56-74 y. old: [1.249 ; 1.800]
Drinking		C	1.822	1.770	2.163	2.018	**1.138**	**0.523**	-	**4.325**	2.527	1.748	30-55 y. old: [1.156 ; 2.221]
		I	2.007	1.845	2.155	1.507	**1.082**	1.320	**4.038**	**4.143**	2.140	1.615	56-74 y. old: [1.518 ; 2.980]
Backward transporting		C	**4.282**	**3.652**	**3.073**	2.667	**3.440**	**4.393**	-	**3.560**	3.338	2.467	30-55 y. old: [2.116 ; 2.967]
		I	**3.323**	**4.078**	2.643	2.605	**3.262**	**3.195**	**4.557**	3.045	2.555	**2.242**	56-74 y. old: [2.417 ; 3.413]
Returning	LIGHT	C	**1.870**	**1.607**	0.800	**0.758**	0.907	**0.767**	0.898	**1.263**	**2.023**	1.227	[0.777 ; 1.245]
		I	**1.283**	**1.407**	**0.647**	**0.713**	0.827	0.860	0.878	**1.335**	**0.715**	1.008	
	DRINK	C	**1.475**	**1.725**	**0.777**	**0.883**	0.925	1.302	-	1.330	**2.583**	**1.527**	[0.901 ; 1.364]
		I	**1.525**	**1.553**	0.932	**0.767**	1.308	1.015	**1.368**	1.122	0.923	**0.865**	
Relative duration (%)													
Reaching	LIGHT	C	55.6	**51.1**	**66.3**	**66.5**	**71.6**	61.2	62.5	56.4	**47.9**	**48.5**	[54.3 ; 62.6]
		I	59.9	58.2	**66.0**	**67.4**	**70.4**	61.9	**70.4**	61.0	61.0	56.2	
	DRINK	C	**25.2**	**26.3**	15.4	16.9	**38.8**	**20.1**	-	16.8	**20.8**	18.6	[14.9 ; 19.7]
		I	**20.5**	15.6	15.9	15.2	**22.6**	**22.3**	**14.2**	**12.9**	**13.4**	15.9	
Forward transporting	DRINK	C	15.4	**13.0**	16.0	17.6	17.4	16.2	-	15.6	**14.2**	16.4	F: [14.4 ; 18.0]
		I	16.0	**15.3**	13.0	15.9	**19.2**	**15.2**	**12.5**	**12.3**	**20.1**	18.7	M: [15.4 ; 18.8]
Drinking		C	14.3	15.0	**24.5**	**23.6**	**9.8**	**6.4**	-	**31.7**	19.4	19.8	[12.3 ; 21.6]
		I	18.6	17.1	**26.8**	21.2	**11.2**	15.0	**29.8**	**37.3**	**25.3**	**22.4**	
Backward transporting		C	33.5	31.0	34.9	31.4	26.6	**44.6**	-	26.1	25.8	27.9	F: [23.4 ; 42.0]
		I	30.8	37.7	32.8	36.8	33.5	36.0	33.5	27.5	30.2	31.0	M: [23.0 ; 39.8]
Returning	LIGHT	C	44.4	**48.9**	**33.7**	**33.5**	**28.4**	38.8	37.5	43.6	**52.1**	**51.5**	Normal BMI: [40.1 ; 49.9]
		I	40.1	41.8	**34.0**	**32.6**	**29.6**	38.1	**29.6**	39.0	**39.0**	43.8	Overweight: [38.0 ; 46.7]
	DRINK	C	**11.6**	14.7	**9.2**	**10.4**	**7.3**	12.4	-	**9.8**	**19.8**	**17.3**	[11.8 ; 16.5]
		I	14.1	14.4	**11.5**	**10.8**	13.5	**11.5**	**10.1**	**10.1**	**11.0**	12.0	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		Reference (*confidence interval of 99%*)
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Mean velocity (m/s)													
Reaching	Light	C	**0.152**	**0.181**	0.239	**0.184**	0.257	**0.391**	**0.174**	0.199	0.284	**0.306**	[0.185 ; 0.293]
		I	**0.158**	**0.160**	0.284	**0.182**	0.195	**0.316**	0.203	0.245	**0.296**	0.273	
	Drink	C	**0.107**	**0.145**	0.283	0.270	**0.176**	0.288	-	**0.204**	**0.207**	0.270	[0.241 ; 0.356]
		I	**0.149**	0.242	0.289	0.345	**0.184**	0.259	**0.230**	0.310	0.345	0.354	
Forward transporting	Drink	C	**0.199**	**0.264**	**0.283**	**0.285**	**0.273**	**0.302**	-	**0.164**	0.289	0.300	30-55 y. old: [0.309 ; 0.430]
		I	**0.239**	**0.281**	0.354	0.347	**0.273**	**0.273**	**0.227**	0.280	0.272	0.323	56-74 y. old: [0.246 ; 0.365]
Drinking	Drink	C	0.071	0.085	**0.058**	**0.050**	0.078	**0.232**	-	0.066	0.053	**0.096**	30-55 y. old: [0.063 ; 0.118]
		I	**0.056**	**0.057**	0.063	0.078	**0.040**	**0.174**	0.060	0.057	0.095	**0.098**	56-74 y. old: [0.050 ; 0.095]
Backward transporting	Drink	C	**0.124**	**0.153**	**0.172**	0.204	0.213	0.235	-	**0.171**	**0.186**	0.242	30-55 y. old: F: [0.188 ; 0.276]|M: [0.211 ; 0.326]
		I	**0.154**	**0.139**	0.192	0.194	**0.186**	**0.205**	**0.138**	0.210	0.252	0.258	56-74 y. old: F: [0.127 ; 0.232]|M: [0.197 ; 0.302]
Returning	Light	C	**0.187**	**0.186**	**0.467**	0.332	**0.564**	**0.657**	0.268	**0.239**	**0.206**	0.260	[0.246 ; 0.390]
		I	**0.234**	**0.208**	**0.552**	0.362	0.361	**0.477**	**0.470**	0.375	**0.433**	0.298	
	Drink	C	**0.265**	**0.234**	**0.475**	0.433	0.393	**0.678**	-	0.332	**0.256**	0.317	[0.294 ; 0.439]
		I	**0.224**	**0.285**	0.397	0.439	0.298	**0.516**	0.320	0.360	**0.453**	**0.504**	
Peak velocity (m/s)													
Reaching	Light	C	**0.505**	**0.431**	0.647	**0.520**	**0.842**	**1.286**	**0.726**	**0.735**	**0.823**	**0.692**	F: 30-55 y. old: [0.611 ; 0.862]|56-74 y. old: [0.548 ; 0.787]
		I	**0.573**	**0.489**	**0.875**	**0.590**	**0.495**	**0.835**	**1.016**	**0.804**	**0.785**	**0.778**	M: 30-55 y. old: [0.575 ; 0.767]|56-74 y. old:[0.494 ; 0.682]
	Drink	C	**0.437**	**0.580**	0.765	0.735	0.728	**0.928**	-	0.627	0.751	**0.913**	[0.624 ; 0.911]
		I	**0.377**	**0.586**	0.741	0.793	**0.517**	0.674	**0.937**	**1.005**	0.892	0.783	
Forward transporting	Drink	C	**0.374**	**0.472**	**0.480**	**0.488**	**0.558**	**0.455**	-	**0.327**	0.634	0.532	30-55 y. old: [0.577 ; 0.822]
		I	**0.482**	0.586	**0.551**	**0.539**	**0.477**	**0.471**	0.478	0.537	0.545	0.621	56-74 y. old: [0.458 ; 0.735]
Drinking	Drink	C	0.128	0.158	0.116	**0.087**	0.166	**0.314**	-	**0.210**	**0.174**	0.142	30-55 y. old: [0.107 ; 0.199]
		I	**0.085**	**0.097**	0.178	0.169	**0.078**	**0.272**	0.108	0.116	0.143	0.146	56-74 y. old: [0.090 ; 0.156]
Backward transporting	Drink	C	**0.457**	**0.374**	0.560	**0.556**	0.696	0.777	-	**0.485**	**0.497**	0.723	30-55 y. old: F: [0.557 ; 0.739]| M: [0.595 ; 0.954]
		I	**0.479**	**0.499**	0.653	0.677	**0.526**	**0.579**	**0.404**	**0.500**	0.604	0.639	56-74 y. old: F: [0.416 ; 0.639]| M: [0.554 ; 0.837]
Returning	Light	C	**0.418**	**0.350**	**1.010**	0.574	**1.048**	**1.249**	0.658	**0.444**	0.494	0.573	[0.463 ; 0.730]
		I	**0.373**	**0.336**	**1.085**	0.643	0.716	**0.902**	**0.878**	0.671	0.725	0.615	
	Drink	C	**0.514**	**0.475**	**0.926**	**0.961**	**0.943**	**1.318**	-	0.735	0.718	0.655	[0.628 ; 0.905]
		I	**0.466**	**0.510**	0.863	0.822	0.644	**0.992**	0.737	0.761	0.835	0.854	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		*Reference (confidence interval of 99%)*
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Relative instant of peak velocity (%)													
Reaching	Light	C	34.9	30.3	**24.8**	26.8	**22.7**	28.9	**18.3**	33.1	33.9	29.6	[26.0 ; 37.4]
		I	33.3	**25.8**	28.4	**25.9**	**24.6**	27.4	**21.0**	33.4	31.0	**25.1**	
	Drink	C	**21.8**	**16.5**	30.8	36.3	**22.8**	**21.8**	-	**27.9**	**22.4**	28.1	[28.0 ; 38.8]
		I	**27.2**	28.9	**44.4**	35.6	**24.7**	**26.5**	**18.0**	**27.6**	29.6	36.4	
Forward transporting	Drink	C	**48.6**	40.8	**44.6**	35.9	**65.0**	**54.7**	-	**48.8**	41.6	33.4	[32.3 ; 42.1]
		I	36.5	40.0	**50.1**	37.8	34.6	**44.3**	34.6	**29.9**	**30.9**	**31.3**	
Backward transporting		C	**34.0**	**38.5**	49.8	**58.6**	**25.6**	**26.4**	-	51.7	**34.9**	**44.8**	[46.5 ; 58.0]
		I	**44.9**	**64.1**	47.4	**46.2**	**27.5**	**25.1**	49.7	**65.2**	52.6	**43.8**	
Returning	Light	C	**41.3**	**37.0**	49.5	56.5	**39.4**	**47.1**	**47.7**	**47.1**	27.4	69.4	F: Normal BMI: [45.4 ; 59.8]| Overweight: [48.3 ; 69.0]
		I	56.4	**51.7**	62.9	54.1	**78.0**	58.3	**51.1**	**52.6**	64.2	**72.8**	M: Normal BMI: [48.4 ; 71.6]| Overweight: [53.3 ; 75.1]
	Drink	C	58.9	64.0	58.6	**78.8**	**83.0**	**28.7**	-	**73.4**	43.3	53.2	[43.2 ; 64.6]
		I	**65.1**	64.6	54.6	**69.4**	61.1	58.3	62.5	**67.6**	63.4	53.9	
Index of curvature													
Reaching	Light	C	1.186	1.249	**1.053**	1.282	**2.396**	1.310	1.331	1.239	**1.982**	1.360	F: [1.108 ; 1.296]
		I	**1.091**	1.200	**1.047**	1.221	**1.648**	1.389	**1.435**	1.351	1.331	1.359	M: [1.164 ; 1.418]
	Drink	C	1.372	**1.507**	**1.130**	1.344	**2.550**	**1.727**	-	1.271	**1.949**	**1.507**	[1.225 ; 1.499]
		I	**1.172**	1.359	**1.161**	1.315	**1.596**	**1.576**	**1.561**	**1.153**	1.385	1.361	
Forward transporting	Drink	C	**1.067**	**1.039**	1.019	1.016	**1.070**	**1.047**	**-**	**1.070**	**1.150**	**1.041**	D limb: [1.012 ; 1.025]
		I	**1.047**	**1.045**	**1.008**	**1.010**	**1.040**	1.020	1.021	1.017	1.024	1.015	ND limb: [1.014 ; 1.035]
Backward transporting		C	**1.117**	1.094	1.056	1.094	**1.483**	**1.694**	-	1.071	**1.161**	1.071	[1.037 ; 1.102]
		I	1.054	1.073	**1.033**	1.073	**1.167**	1.133	**1.107**	**1.152**	**1.036**	**1.029**	
Returning	Light	C	1.183	1.168	**1.033**	1.093	**1.853**	1.254	1.261	1.195	**1.657**	1.182	F: [1.066 ; 1.230]
		I	**1.074**	1.104	**1.047**	1.104	1.218	1.207	**1.338**	**1.308**	1.152	1.145	M: [1.101 ; 1.295]
	Drink	C	**1.479**	1.305	**1.105**	1.223	1.163	**2.063**	-	**1.152**	**2.175**	**1.610**	[1.197 ; 1.440]
		I	1.205	1.383	**1.115**	**1.120**	**1.460**	1.433	**1.649**	**1.185**	1.389	1.350	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		REFERENCE (confidence interval of 99%)
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Number of movement units													
Reaching	LIGHT	C	**3.3**	**2.3**	**2.3**	**2.0**	**6.3**	**2.3**	**4.3**	**3.0**	**4.3**	1.7	30-55 y. old: [1.0 ; 1.7] 56-74 y. old: [1.3 ; 2.5]
		I	1.0	1.3	1.7	1.0	**3.0**	**2.3**	**2.7**	1.5	1.3	1.7	
	DRINK	C	**4.0**	**4.0**	1.0	**1.7**	**7.0**	**6.7**	-	1.3	**6.7**	**2.7**	[0.9 ; 1.6]
		I	1.0	1.0	1.0	1.3	**2.3**	**3.3**	**1.7**	1.0	1.0	**1.7**	
Forward transporting	DRINK	C	**2.7**	**1.7**	1.0	1.0	**4.3**	**5.0**	-	**4.0**	**4.0**	**2.0**	1.0
		I	1.0	1.0	1.0	1.0	1.0	**1.7**	1.0	1.0	1.0	1.0	
Drinking		C	**4.3**	**3.0**	**2.0**	1.3	1.3	0.3	-	**7.7**	**5.7**	**4.7**	[0.9 ; 1.6]
		I	**0.7**	**0.7**	**0.7**	**3.0**	**0.7**	**2.0**	**4.7**	**3.7**	**2.3**	**2.7**	
Backward transporting		C	**6.7**	**6.7**	2.0	2.3	**8.5**	**14.7**	-	**5.7**	**6.3**	2.7	[1.9 ; 3.3]
		I	**4.0**	2.7	2.3	3.3	**4.0**	**5.0**	**5.7**	**4.3**	2.0	**1.7**	
Returning	LIGHT	C	**2.3**	**3.3**	1.0	1.0	**1.7**	**1.7**	2.3	1.5	**4.7**	**2.7**	30-55 y. old: [1.0 ; 1.5] 56-74 y. old: [1.1 ; 2.3]
		I	1.0	**2.0**	1.0	1.0	1.0	1.3	1.0	1.0	1.0	1.7	
	DRINK	C	**2.7**	**3.0**	**1.0**	2.0	**2.5**	**3.0**	-	1.7	**5.0**	**2.7**	[1.1 ; 2.0]
		I	1.7	2.0	1.3	1.0	**2.3**	**3.0**	2.0	2.0	2.0	2.0	
Maximum magnitude of hand aperture (m)													
Reaching	DRINK	C	**0.102**	**0.100**	**0.104**	**0.103**	**0.151**	**0.144**	-	0.119	0.112	0.119	[0.112 ; 0.129]
		I	**0.105**	**0.108**	**0.107**	**0.111**	**0.142**	**0.147**	0.119	**0.107**	0.126	0.128	
Returning		C	**0.106**	**0.096**	**0.099**	**0.100**	0.115	0.128	-	**0.094**	**0.097**	0.119	30-55 y. old: [0.110 ; 0.128] 56-74 y. old: [0.104 ; 0.121]
		I	**0.105**	0.121	0.110	**0.108**	0.121	**0.138**	**0.127**	0.119	0.115	0.119	
Relative instant of maximum hand aperture (%)													
Reaching	DRINK	C	**50.9**	**52.8**	69.1	69.9	**50.2**	67.0	-	63.9	67.6	64.9	[61.1 ; 76.6]
		I	**59.8**	70.3	**79.4**	72.0	**59.5**	62.8	**42.8**	64.3	**60.3**	65.9	
Returning		C	25.6	**41.6**	24.5	**38.2**	**51.0**	**62.8**	-	31.5	20.3	**36.5**	[20.3 ; 33.9]
		I	**35.7**	26.5	24.7	28.8	27.6	**67.0**	29.6	29.5	29.6	31.7	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		REFERENCE *(confidence interval of 99%)*
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Shoulder flexion-extension angle offset (°)													
Reaching	LIGHT	C	42.5	34.2	**45.3**	36.6	40.2	36.0	43.6	**34.8**	50.0	44.2	30-55 y. old: [32.8 ; 44.7] 56-74 y. old: [35.8 ; 50.8]
		I	**23.5**	**22.4**	42.3	38.8	37.1	34.0	**56.6**	44.4	45.4	47.2	
	DRINK	C	**36.2**	**36.0**	43.0	44.6	42.6	52.8	-	45.7	52.3	50.7	[41.1 ; 54.0]
		I	**29.4**	**33.5**	**39.0**	47.0	43.0	44.4	51.7	43.1	52.6	49.6	
Forward transporting		C	52.1	49.5	46.1	54.6	57.3	**77.0**	-	**36.1**	52.3	47.7	[43.7 ; 58.1]
		I	**37.3**	**41.1**	48.7	57.7	**59.9**	48.9	45.1	**43.2**	**40.5**	**41.4**	
Drinking		C	71.0	72.9	69.8	73.7	**60.1**	80.9	-	**64.1**	68.4	71.8	[67.5 ; 81.8]
		I	**56.0**	**58.0**	77.1	81.3	**62.5**	71.6	75.1	76.9	**65.6**	**62.6**	
Backward transporting		C	**38.1**	**39.0**	43.0	45.5	**35.7**	51.7	-	46.3	55.3	52.1	[43.0 ; 56.1]
		I	**30.7**	**35.8**	**40.3**	47.9	47.7	46.6	50.9	**42.9**	51.6	50.0	
Shoulder adduction-abduction angle offset (°)													
Reaching	LIGHT	C	**-21.2**	**-29.4**	-16.8	-16.0	**-5.4**	**-21.8**	-13.7	-16.2	**-23.6**	**-17.8**	Normal BMI: D limb: [-16.9 ; -6.0]| ND limb: [-15.5 ; -1.6] Overweight: D limb: [-21.9 ; -9.8]| ND limb: [-18.1 ; -7.3]
		I	**-27.3**	**-26.7**	-15.1	-8.4	**-6.8**	-13.4	-18.1	-20.8	-9.8	-10.7	
	DRINK	C	**-23.8**	**-25.8**	-17.8	-18.5	-9.9	**-41.7**	-	-15.0	**-20.5**	-14.8	D limb: [-20.6 ; -8.9] ND limb: [-18.9 ; -4.3]
		I	-16.8	**-22.0**	-15.5	-10.0	-11.6	-17.2	-16.1	**-22.2**	**-7.0**	-9.0	
Forward transporting		C	**-22.9**	**-32.4**	-12.2	-16.6	**-1.2**	**-36.8**	-	-8.9	-18.1	-6.8	F: D limb: [-22.9 ; -4.5]| ND limb: [-16.0 ; 2.7] M: [-22.3 ; -5.8]
		I	**-30.2**	**-30.7**	**-18.3**	-10.4	-9.4	-7.8	-22.1	**-29.5**	-6.5	-5.8	
Drinking		C	**-27.2**	**-35.0**	-13.0	-20.3	**-0.6**	**-35.1**	-	-5.0	**-24.4**	-8.5	D limb: [-27.8 ; -11.5] ND limb: [-24.4 ; -3.4]
		I	**-32.2**	**-34.2**	-21.3	-16.0	**-10.4**	**-10.4**	**-30.9**	**-39.4**	**-9.0**	**-8.4**	
Backward transporting		C	**-19.7**	**-24.3**	-13.3	-17.0	-6.9	**-36.1**	-	-9.2	**-25.0**	-15.9	D limb: [-20.6 ; -8.9] ND limb: [-19.2 ; -4.6]
		I	**-22.3**	**-21.2**	-12.6	-8.6	-11.6	-19.6	-19.9	**-23.8**	-9.6	**-7.2**	
Shoulder medial rotation-lateral rotation angle offset (°)													
Reaching	LIGHT	C	35.0	28.9	**43.8**	**42.2**	31.1	**15.0**	**10.6**	**15.3**	38.1	25.8	[25.7 ; 41.5]
		I	**22.4**	**13.8**	38.5	**41.9**	25.8	26.4	35.8	30.0	30.2	30.6	
	DRINK	C	29.2	20.3	**41.5**	**37.5**	29.6	**36.8**	-	**19.1**	26.7	23.2	[19.7 ; 36.7]
		I	**17.3**	**12.4**	36.4	**37.4**	26.9	29.1	31.2	24.7	**19.5**	**19.2**	
Forward transporting		C	39.6	32.0	38.5	39.7	**43.2**	**56.7**	-	28.5	33.7	32.6	[25.4 ; 41.4]
		I	25.5	**19.1**	**43.2**	**45.2**	36.5	**44.2**	40.0	**41.5**	26.7	**24.9**	
Drinking		C	36.6	29.5	32.4	36.8	**45.5**	**56.0**	-	23.6	28.8	30.0	[22.7 ; 39.4]
		I	23.7	**17.0**	**41.4**	**42.1**	37.5	38.9	39.3	**44.5**	25.1	**22.1**	
Backward transporting		C	31.9	25.5	37.4	35.9	28.0	38.4	-	**18.7**	32.8	26.9	[22.6 ; 39.6]
		I	**18.8**	**14.9**	35.5	38.2	32.7	33.7	**40.3**	29.4	**21.2**	**18.9**	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		REFERENCE *(confidence interval of 99%)*
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Elbow flexion-extension angle offset (°)													
Reaching	LIGHT	C	**72.2**	85.9	**66.3**	79.1	78.3	**93.9**	70.6	**92.7**	**66.8**	**67.9**	Normal BMI: [66.9 ; 86.1] Overweight: [73.1 ; 92.3]
		I	89.8	89.3	**67.3**	**69.7**	77.0	90.0	**60.4**	76.8	**67.1**	**61.1**	
	DRINK	C	**71.1**	**74.1**	69.8	66.1	**72.1**	**110.8**	-	**75.1**	58.5	61.6	F: [58.2 ; 77.6] M: [50.9 ; 69.2]
		I	**73.6**	**73.6**	66.1	65.7	**80.7**	**104.0**	60.6	67.7	55.5	59.8	
Forward transporting	DRINK	C	**121.6**	**127.2**	136.2	138.2	**127.7**	**129.4**	-	**125.4**	**124.9**	**129.9**	F: [133.6 ; 142.7] M: [130.4 ; 138.5]
		I	**139.0**	**140.8**	**132.7**	**132.9**	132.6	133.7	**130.1**	132.1	134.2	131.1	
Drinking	DRINK	C	**120.1**	**122.4**	132.8	133.1	127.9	127.3	-	**117.6**	127.5	**124.6**	[125.6 ; 135.9]
		I	134.5	**136.8**	130.9	130.1	132.0	128.6	**125.0**	**125.1**	127.7	125.7	
Backward transporting	DRINK	C	**69.1**	**67.4**	67.5	62.8	**80.0**	**86.0**	-	**74.0**	57.1	62.6	F: [53.4 ; 73.4] M: [48.7 ; 66.1]
		I	**72.0**	**66.7**	65.8	63.9	57.8	**83.9**	55.5	**66.4**	53.6	56.3	
Elbow pronation-supination angle offset (°)													
Reaching	LIGHT	C	**138.7**	161.9	**93.5**	148.5	**114.4**	**142.0**	**135.1**	161.0	**124.8**	142.1	30-55 y. old: [147.7 ; 167.2] 56-74 y. old: [141.6 ; 166.3]
		I	155.0	153.4	**76.2**	154.2	148.3	**142.8**	**123.2**	**131.4**	154.3	153.8	
	DRINK	C	116.5	112.3	**98.5**	105.9	101.2	**98.9**	-	112.6	**82.6**	102.3	30-55 y. old: [99.7 ; 124.0] 56-74 y. old: [90.9 ; 120.4]
		I	121.8	122.8	**98.6**	107.3	**133.5**	111.3	97.5	107.4	**121.8**	119.8	
Forward transporting	DRINK	C	**118.8**	**103.9**	127.2	139.6	136.0	**117.0**	-	**112.7**	**83.5**	120.4	30-55 y. old: [124.4 ; 155.1]
		I	136.4	127.8	**121.8**	131.4	**164.5**	144.3	**112.7**	120.4	140.2	**145.4**	56-74 y. old: [113.8 ; 145.1]
Drinking	DRINK	C	131.4	**114.6**	135.7	144.0	135.2	**118.7**	-	120.8	**97.9**	125.7	30-55 y. old: [129.7 ; 156.5] 56-74 y. old: [120.4 ; 151.8
		I	153.7	141.9	130.5	138.3	**164.8**	150.5	121.2	129.3	148.3	**152.7**	
Backward transporting	DRINK	C	117.9	106.7	106.1	108.9	**99.4**	102.9	-	**121.5**	97.1	103.5	30-55 y. old: [99.8 ; 124.1] 56-74 y. old: [91.2 ; 120.7]
		I	122.0	120.0	101.4	104.0	**127.9**	106.4	97.0	107.8	**124.1**	**126.7**	
Wrist flexion-extension angle offset (°)													
Reaching	LIGHT	C	3.2	10.7	**-2.8**	**-3.5**	**-4.2**	**-10.1**	7.0	5.5	11.8	3.0	[0.5 ; 19.4]
		I	7.8	8.2	**-12.4**	**-8.6**	**-4.2**	**-17.4**	**-1.8**	**-6.8**	**-1.7**	4.4	
	DRINK	C	-5.9	6.6	**-9.0**	**-4.7**	**-12.5**	**-10.0**	-	**10.8**	8.2	2.1	F: [-1.7 ; 13.0] M: [-6.2 ; 10.7]
		I	-5.4	-4.3	**-13.2**	**-6.1**	**-17.2**	**-12.9**	3.4	-2.7	**-6.4**	-1.8	
Forward transporting	DRINK	C	2.9	10.2	**-0.3**	6.4	**-21.1**	**-14.8**	-	11.9	**34.8**	5.7	F: [4.3 ; 19.4] M: [-4.1 ; 12.4]
		I	10.2	9.8	**-7.0**	**-0.4**	**-7.6**	**-15.5**	**-4.6**	**-11.3**	7.2	8.4	
Drinking	DRINK	C	-3.7	**10.8**	**-6.6**	-1.9	**-20.9**	**-15.1**	-	**9.3**	**39.7**	-0.5	F: [-4.5 ; 13.2] M: [-9.4 ; 6.5]
		I	1.7	3.0	**-12.2**	-3.8	-5.6	**-22.6**	**-9.8**	**-17.0**	-4.8	-1.5	
Backward transporting	DRINK	C	1.0	6.4	**-7.3**	**-3.4**	**-22.6**	**-16.5**	-	**12.3**	**15.5**	2.3	F: [-2.6 ; 12.9] M: [-7.3 ; 9.7]
		I	-0.9	-3.1	**-7.3**	-0.8	**-17.9**	**-18.1**	-1.8	**-9.8**	-6.5	-2.5	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1*		*Patient 2*		*Patient 3*		*Patient 4*		*Patient 5*		Reference (confidence interval of 99%)
			T1	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	*T1*	*T2*	
Wrist ulnar deviation-radial deviation angle offset (°)													
Reaching	Light	C	**-4.2**	**10.3**	**22.0**	16.4	20.3	21.6	**7.0**	**7.7**	13.4	15.3	[11.0 ; 21.9]
		I	**8.3**	**9.9**	**24.2**	17.9	15.3	13.9	14.8	**3.5**	**10.4**	13.2	
	Drink	C	**-9.1**	**-11.3**	5.4	2.0	**12.8**	**17.3**	-	2.3	**10.4**	**10.2**	[-3.4 ; 9.7]
		I	3.2	-0.1	4.7	6.7	**18.5**	**14.4**	-0.4	**-4.9**	7.8	7.4	
Forward transporting	Drink	C	**-5.0**	**-7.0**	24.2	18.8	**14.3**	**14.9**	-	**6.3**	20.6	25.2	[17.0 ; 27.2]
		I	17.9	**12.7**	19.6	19.9	25.3	**14.6**	18.2	**12.4**	19.3	20.2	
Drinking	Drink	C	**-8.7**	**-14.2**	17.0	14.2	15.0	13.8	-	**-3.9**	15.5	13.9	30-55 y. old: D limb:[10.7 ; 22.6]|ND limb:[6.6 ; 20.6] 56-74 y. old: D limb:[8.0 ; 21.7]| ND limb:[1.9 ; 18.8]
		I	15.9	**6.7**	12.8	12.7	22.2	**10.5**	11.4	**6.3**	12.2	14.1	
Backward transporting	Drink	C	**-8.8**	**-10.7**	3.5	-2.1	**17.4**	6.0	-	0.1	**10.9**	6.8	[-5.6 ; 7.7]
		I	4.6	-2.4	2.2	4.7	**12.6**	5.4	-1.7	-2.7	5.8	2.7	
Trunk displacement in sagittal plane (m)													
Reaching	Light	C	**-0.005**	-0.002	**-0.006**	0.000	**0.023**	**0.071**	0.003	**0.024**	**-0.009**	**0.009**	[-0.002 ; 0.006]
		I	0.000	-0.002	**-0.014**	**-0.005**	**0.015**	**0.062**	0.002	-0.001	0.003	**0.008**	
	Drink	C	0.014	**0.043**	0.004	**0.002**	**0.055**	**0.175**	-	**0.049**	**0.031**	**0.027**	[0.004 ; 0.026]
		I	0.005	0.018	**-0.006**	**-0.002**	**0.061**	**0.133**	0.019	0.008	0.013	**0.030**	
Forward transporting	Drink	C	-0.007	**-0.021**	-0.003	-0.001	**-0.063**	**-0.164**	-	-0.008	**-0.038**	-0.010	[-0.017 ; 0.000]
		I	-0.006	-0.016	**0.001**	-0.003	**-0.054**	**-0.078**	-0.010	-0.007	**-0.019**	-0.015	
Drinking	Drink	C	-0.005	**-0.014**	-0.003	0.001	0.000	**-0.052**	-	**-0.053**	**-0.007**	**-0.011**	[-0.005 ; 0.003]
		I	-0.002	-0.004	-0.003	0.001	**-0.006**	**-0.052**	**-0.033**	**-0.032**	**-0.020**	**-0.008**	
Backward transporting	Drink	C	**0.003**	**0.019**	0.005	**0.003**	**0.061**	**0.146**	-	**0.058**	**0.049**	**0.037**	[0.004 ; 0.018]
		I	0.007	0.009	0.005	**0.003**	**0.021**	**0.091**	**0.040**	**0.040**	**0.039**	**0.026**	
Returning	Light	C	**0.004**	-0.002	**0.005**	0.001	**-0.003**	**-0.029**	**0.006**	**-0.021**	**0.004**	**-0.009**	[-0.002 ; 0.003]
		I	-0.001	0.001	**0.008**	0.002	**0.006**	**-0.004**	0.002	-0.002	**-0.003**	**-0.006**	
	Drink	C	**0.003**	**-0.034**	-0.003	-0.002	**-0.025**	**-0.105**	-	**-0.040**	**-0.022**	**-0.030**	[-0.015 ; 0.002]
		I	**0.007**	-0.011	**0.008**	0.000	-0.004	**-0.051**	**-0.018**	0.000	**-0.019**	**-0.022**	

(continued)

Table 2. *(continued)*

Kinematics	*Task*	*UL*	*Patient 1* T1	*Patient 1* T2	*Patient 2* T1	*Patient 2* T2	*Patient 3* T1	*Patient 3* T2	*Patient 4* T1	*Patient 4* T2	*Patient 5* T1	*Patient 5* T2	Reference (*confidence interval of 99%*)
Trunk displacement in frontal plane (m)													
Reaching	Light	C	**0.005**	0.001	-0.002	0.000	**-0.007**	**-0.003**	**-0.009**	**0.011**	**-0.017**	0.000	[-0.002 ; 0.001]
		I	-0.002	**-0.003**	**-0.003**	**-0.003**	**0.002**	**0.011**	**-0.006**	**-0.003**	-0.001	0.000	
	Drink	C	**0.008**	**0.021**	0.002	0.002	-0.002	**0.009**	-	**0.018**	**-0.001**	**-0.002**	30-55 y. old: [-0.002 ; 0.006] 56-74 y. old: [0.001 ; 0.009]
		I	-0.002	0.002	**-0.004**	-0.001	**0.012**	0.006	**-0.003**	0.002	0.002	0.007	
Forward transporting	Drink	C	0.000	-0.004	-0.003	-0.003	0.000	**-0.023**	-	-0.003	**0.004**	0.002	[-0.005 ; 0.002]
		I	0.001	0.000	-0.001	-0.001	-0.005	0.002	**0.003**	**0.004**	-0.005	-0.002	
Drinking	Drink	C	**0.001**	-0.001	-0.001	-0.004	**-0.006**	**0.001**	-	**0.006**	**0.005**	-0.001	[-0.004 ; 0.000]
		I	-0.003	**-0.005**	-0.003	-0.002	-0.001	0.000	**-0.010**	**-0.014**	**-0.009**	**-0.005**	
Backward transporting	Drink	C	0.004	0.003	0.004	0.003	**-0.001**	**0.025**	-	**0.010**	**-0.003**	0.005	30-55 y. old: [0.001 ; 0.008] 56-74 y. old: [0.003 ; 0.009]
		I	0.003	0.005	0.005	0.003	**-0.002**	**-0.011**	0.005	0.007	**0.012**	0.006	
Returning	Light	C	**-0.006**	0.000	0.000	-0.001	**0.005**	0.001	**0.012**	**-0.009**	**0.009**	-0.001	[-0.001 ; 0.002]
		I	0.000	0.000	-0.001	0.000	**0.003**	-0.001	**0.006**	**0.004**	0.002	0.000	
	Drink	C	**0.004**	**-0.018**	-0.002	0.000	0.002	**-0.023**	-	**-0.027**	**-0.007**	0.000	[-0.005 ; 0.003]
		I	0.003	-0.004	0.002	-0.001	0.003	**0.010**	-0.005	0.002	0.002	-0.003	
Trunk displacement in transverse plane (m)													
Reaching	Light	C	**0.010**	0.002	0.000	0.002	**0.004**	**0.007**	**0.015**	**0.008**	**0.007**	**0.004**	[0.000 ; 0.003]
		I	0.001	0.001	**-0.003**	0.001	0.001	0.002	0.002	0.001	0.002	**0.004**	
	Drink	C	0.003	**0.007**	0.000	0.002	**0.007**	-0.001	-	0.003	0.005	**0.007**	30-55 y. old: [-0.001 ; 0.004] 56-74 y. old: [0.001 ; 0.006]
		I	0.004	0.002	-0.001	0.000	0.004	**0.012**	0.005	0.002	0.006	**0.007**	
Forward transporting	Drink	C	0.003	0.002	0.002	0.002	0.001	**0.021**	-	0.003	0.002	0.003	[0.000 ; 0.004]
		I	0.002	0.001	0.002	0.002	0.004	**0.007**	0.000	0.002	0.001	0.001	
Drinking	Drink	C	0.006	0.006	0.002	0.004	0.003	**-0.001**	-	**0.007**	0.004	0.006	[0.002 ; 0.006]
		I	0.006	**0.007**	0.003	0.005	0.002	**0.009**	**0.010**	**0.008**	**0.012**	**0.008**	
Backward transporting	Drink	C	-0.008	-0.007	-0.006	-0.005	**-0.002**	-0.004	-	**-0.012**	**-0.002**	-0.003	[-0.008 ; -0.003]
		I	-0.006	-0.007	-0.005	-0.005	-0.004	-0.007	-0.005	-0.007	-0.007	-0.006	
Returning	Light	C	**-0.008**	-0.003	**0.001**	-0.002	-0.002	-0.001	**-0.008**	**-0.008**	**-0.005**	-0.003	[-0.003 ; -0.001]
		I	-0.001	-0.002	**0.001**	**0.000**	**0.000**	**0.001**	-0.001	-0.001	-0.002	**-0.004**	
	Drink	C	**-0.008**	**-0.005**	**0.001**	-0.001	-0.004	**-0.007**	-	**0.001**	**-0.009**	**-0.005**	[-0.004 ; 0.000]
		I	**-0.006**	-0.003	**0.002**	0.000	**-0.005**	**-0.007**	-0.003	**0.001**	**-0.006**	-0.004	

Abbreviation: BMI – body mass índex; C – Contralesional; D limb: dominant limb; F: Female; I: Ipsilesional; m- meter; M: Male; T1: early acute phase after stroke; T2: beginning of chronic phase after stroke; ND limb: non-dominant limb; s: second; UL: upper limb; y. old: years old.

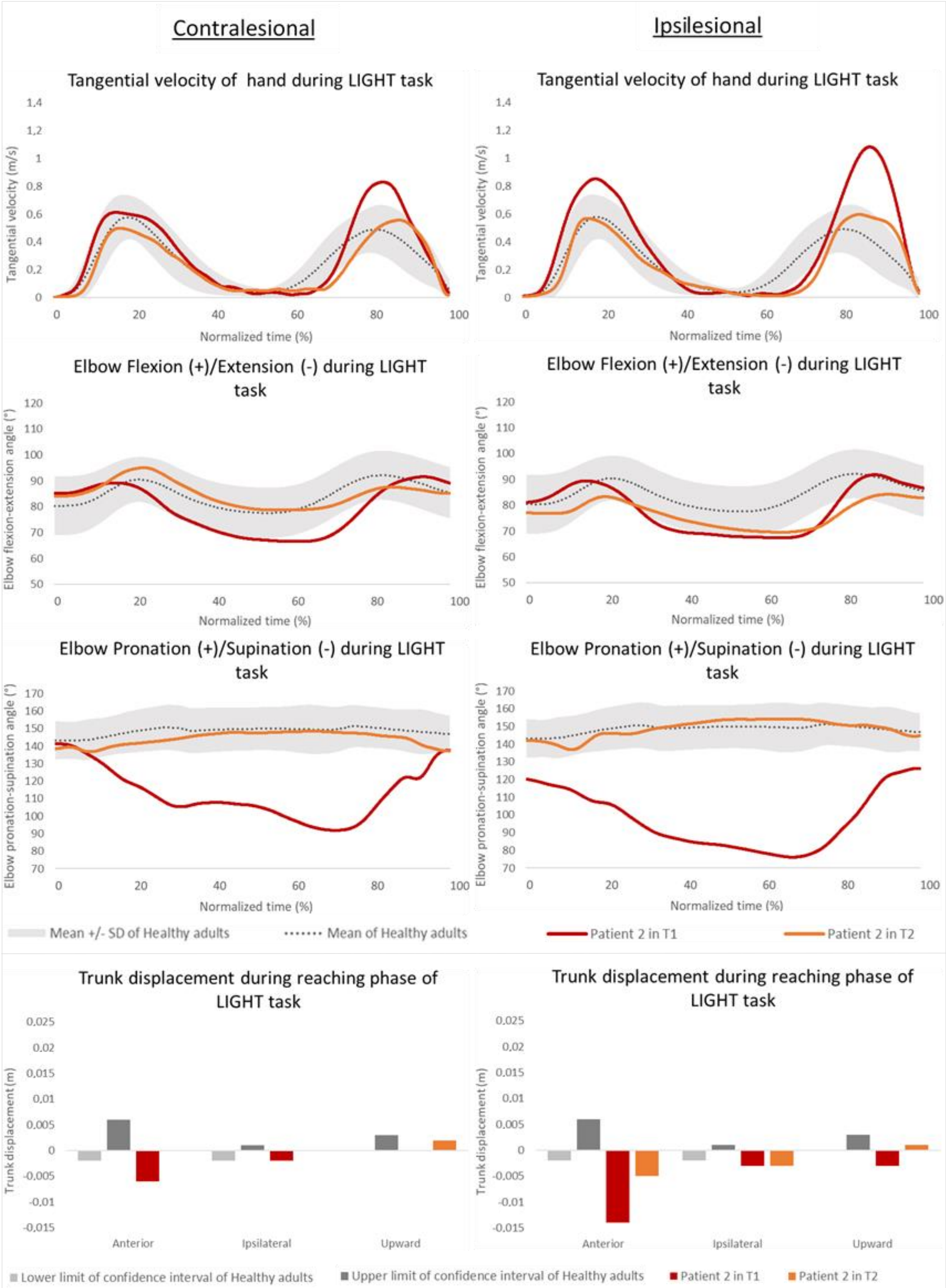

Figure 2. Some of the main kinematic alterations of Patient 2 in T1 and T2.

3.2 Patient 2

In T1, patient 2 presented bilateral kinematic changes, especially in index of curvature and in wrist angle, and during reaching of LIGHT task. Index of curvature of both ULs was lower than the reference in almost all phases of both tasks and both wrists presented excessive extension in all phases of both tasks. In reaching of LIGHT, both ULs had lower elbow flexion, lower forearm pronation, greater wrist ulnar deviation and an excessive posterior trunk displacement. It is also noteworthy that during reaching of DRINK, when comparing to the reference, both hands opened less than expected, and cUL was slower in forward transporting, drinking and backward transporting and faster in the returning of both tasks.

In T2, patient 2 improved most of the alterations presented in T1, with the exception of the hand aperture which remained similarly low. In addition, some worsening effects were noted, such as: the slower reaching of LIGHT with both ULs; the longest duration of forward transporting with cUL, and its longest time required for maximum hand aperture during the returning of DRINK; the excessive medial rotation of ipsilesional shoulder in the transition between all phases of both tasks, and the slightest smoothness of the same UL in drinking phase.

3.3 Patient 3

In T1, patient 3 presented several bilateral alterations in all phases and tasks evaluated (more subtly in iUL). In almost all phases, he was the patient with the highest NMU and absolute duration (with the exception of the drinking phase, which took less time than normal). In almost all phases, he also had an excessive anteroposterior displacement of the trunk, a high index of curvature and an excessive wrist extension. In addition, during the reach of the glass, he opened both hands more and earlier than the reference.

In T2, some alterations improved but many others got worse. Index of curvature decreased, with the exception of backward transporting and returning of DRINK with contralesional hand, in which it increased significantly. In these

Figure 3. Some of the main kinematic alterations of Patient 3 in T1 and T2.

two phases (especially in backward transporting) and in forward transporting, the NMU also increased bilaterally. Backward transporting with cUL seems to have been particularly difficult in T2, since in addition this patient also took longer to perform it. Other variables that worsened considerably, compared to T1, was trunk displacement, especially in the sagittal plane. In this plane, the trunk moved excessively in all phases of both tasks, with magnitudes higher than in T1. It should also be noted that mean and peak velocities were excessive in both phases of LIGHT task, as well as in drinking and returning phases of DRINK task, when compared to T1; both hands took longer to got maximum aperture during the returning of DRINK; contralesional shoulder had excessive abduction in all transitions between phases of both tasks, and excessive medial rotation at the end of drinking and forward and backward transporting.

3.4 Patient 4

In T1, patient 4 scored less than 8 in "Hand" section of FMA-UE - incompatible with the ability to perform the DRINK task with cUL. However, he was able to perform the LIGHT task with this UL and some alterations were observed especially in reaching, when comparing to the reference values. He took longer and was slower to reach the switch, having started the deceleration earlier than expected. In addition, the hand movement was not smooth and the trunk moved excessively upwards and in the contralateral direction. iUL presented several alterations, especially in DRINK task. In most phases of this task, iUL was slower, took longer to perform them and presented excessive index of curvature, NMU and medial-lateral displacement of the trunk. Also noteworthy was his excessive shoulder abduction at the end of the drinking phase.

In T2, this patient obtained the maximum score in the "Hand" section, being able to perform the DRINK task with cUL. However, it presented several alterations in most phases, such as: high NMU and absolute duration; excessive trunk displacement in sagittal and frontal planes; and lower mean velocity, hand aperture and shoulder flexion. In reaching of LIGHT task, cUL decreased

Figure 4. Some of the main kinematic alterations of Patient 4 in T1 and T2.

shoulder flexion and increased elbow flexion and trunk displacement in the anterior and ipsilateral direction. This UL also slows down in the returning of the same task, taking longer to complete it. There have been several improvements in iUL, with the exceptions of: shoulder abduction and wrist extension, that increased in most phases of DRINK task; hand aperture for release, that decreased; absolute duration of drinking and returning in LIGHT, that increased; and index of curvature of backward transporting, which was higher.

3.5 Patient 5

In T1, patient 5 presented kinematic alterations in both ULs, but mainly in the cUL. The efficiency and smoothness of contralesional hand movement were reduced in all phases and tasks evaluated. In addition, in almost every phases, when cUL moved, it was possible to observe an excessive trunk displacement in at least one direction, excessive shoulder abduction and wrist flexion, as well as lower forearm pronation. This hand also opened earlier to grasp the glass and with lesser magnitude during returning. Regarding iUL, the excessive anteroposterior trunk displacement in all phases (except reaching) is noteworthy.

In T2, most of the abnormal values of cUL observed in T1 normalized or improved. In contrast, iUL worsened in some kinematics, such as the trunk displacement in the sagittal and transverse plane during the reaching of both tasks and in the instant of peak velocity in almost all phases. In addition, shoulder medial rotation was low and forearm pronation high in most phases.

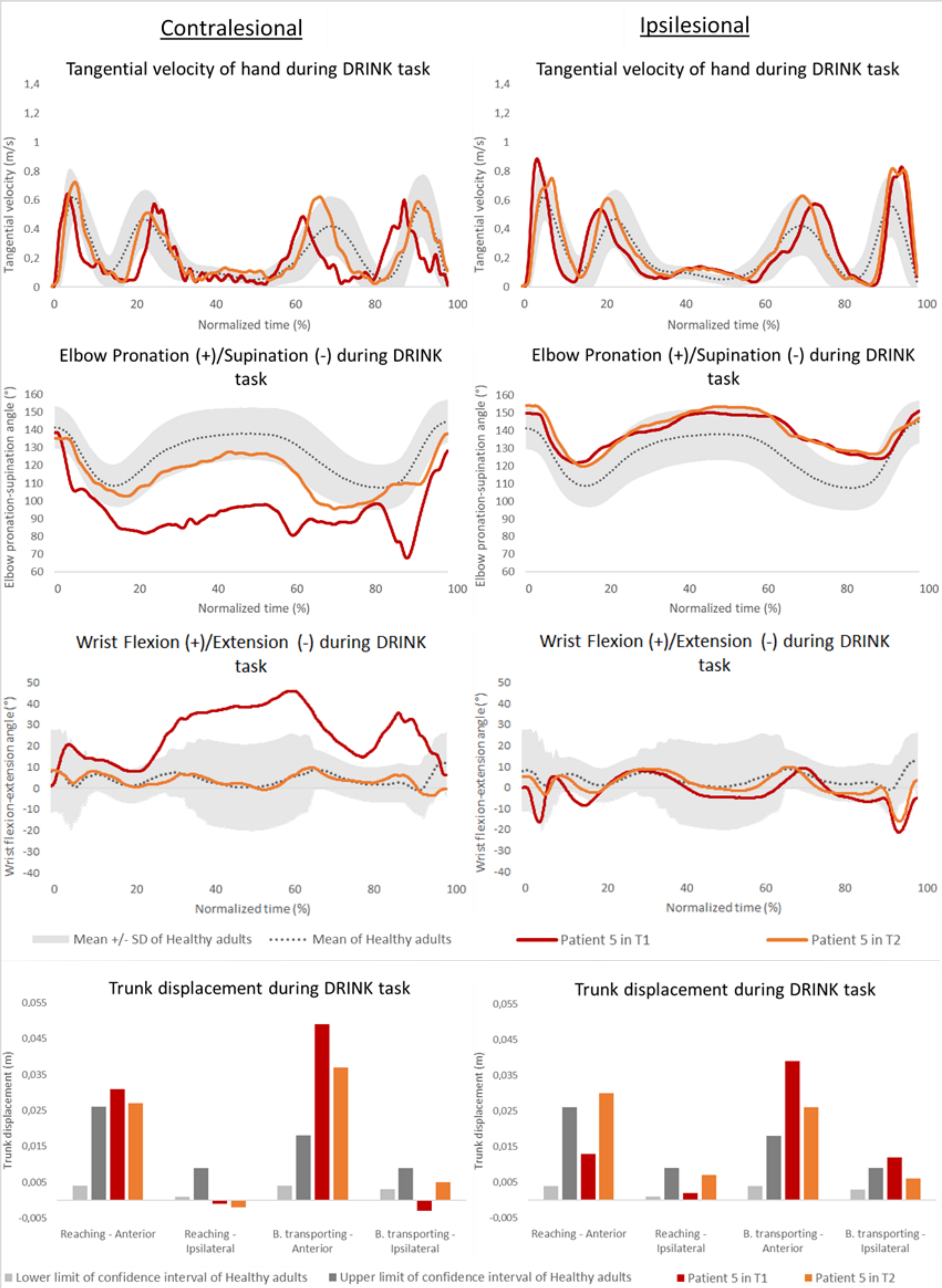

Figure 5. Some of the main kinematic alterations of Patient 5 in T1 and T2.

4. Discussion

In this case series, both ULs of five poststroke adults were kinematically analysed in the early subacute phase and in the beginning of chronic phase. The early subacute phase was selected since the movement pattern presented results mainly from the spontaneous recovery process (Carrera & Tononi, 2014; Grefkes & Fink, 2011; Ward & Cohen, 2004). In the beginning of chronic phase, the improvement of impairments and function seems to be less marked (Bernhardt et al., 2017), due to maturation of re-organization processes in the neural networks (Karnath & Rennig, 2017; Ward & Cohen, 2004). Therefore, the analysis of these two moments may allow observing the evolution of motor performance towards restitution or compensation.

The following sections discuss the key results about the kinematic strategies of both ULs of the five poststroke adults studied, as well as their implications for stroke rehabilitation and future research.

4.1 Kinematic strategies of both upper limbs of poststroke adults

In this case series, differences were found between the kinematic strategies used by poststroke adults to perform DRINK and LIGHT tasks and those of previously studied healthy adults (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). All patients presented kinematic alterations in both ULs, in the early sub-acute phase (T1) and in the beginning of chronic phase (T2), although, in most cases, the differences were more subtle in the iUL and their extent have decreased from T1 to T2. Though most of these alterations were in the expected direction, such as less smoothness of movement, greater trunk displacement, etc., in some patients, some variables showed values that were not expected, i.e., apparently "better" than those of the healthy reference, namely duration, velocity and index of curvature. Future studies will need to clarify whether shorter duration, higher speed and lower index of curvature than healthy reference may be associated with higher quality motor performance, or may be related to poor motor control of the ULs and consequently with poor motor performance.

4.1.1 Drinking and turning on the light tasks

DRINK task has been previously studied (Bustren et al., 2017; Kim et al., 2014; Murphy et al., 2013; Murphy et al., 2012; Murphy et al., 2011; Thies et al., 2009) to analyse kinematic strategies of poststroke adults. However, no other study has so comprehensively analysed DRINK task in this population. Only patient 4 was unable to perform this task with the cUL in T1, as he had a considerable impairment in the ability to open and close the hand, as well as in various types of grip function, according to the “Hand” section of FMA-UE. On the other hand, all patients were able to perform the LIGHT task with both ULs, separately, since interaction with the switch seems to be easier (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). The switch is a flat target whose interaction consists of being pressed without the hand exceeding its limit. The glass is a cylindrical object, whose interaction implies that the hand overtakes it laterally and then grasps it (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). Although targets were placed in the same position, their different shape and interaction result in a reaching movement with different requirements (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). In typical LIGHT task, the hand is carried upwards and forwards, through shoulder flexion and elbow extension, pressing the switch in a prone position, with slight wrist flexion and ulnar deviation (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). In typical DRINK task, the hand is carried to a lateral position to the glass through a greater shoulder flexion and a greater elbow extension, combined with shoulder lateral rotation, with a simultaneous pre-shaping of the fingers for grasping the glass (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). This different interaction results in a longer end-point trajectory to grasp the glass than that required to press the switch. In both moments, the difficulty in recruiting greater shoulder flexion and elbow extension was evident in patient 1, especially in the cUL. Probably to compensate this difficulty, this patient increased shoulder abduction, wrist radial deviation and anterior trunk displacement (especially in T2). Although apparently easier, reaching the switch with proper forearm orientation (in pronation) was also difficult for all patients in T1. However, for patients 2 and 3, this difficulty may have resulted of the re-organization processes in the neural networks (Karnath & Rennig, 2017; Ward & Cohen, 2004) presented in T1, since they were able to obtained higher pronation angles in DRINK task.

In T1, one of the kinematics with the most changes in both DRINK and LIGHT reaching was NMU. Most patients presented high NMU in reaching of both tasks with cUL, but NMU of DRINK tended to be higher than that of LIGHT one, which may resulted of the most demanding hand trajectory to grasp the glass. According to this alteration, there was also the absolute duration of reaching to grasp the glass with cUL, which was elevated in T1 in most patients, and the excessive anterior trunk displacement presented by patients 3 and 5. Murphy et al. (2011) also found high NMU and absolute duration during reaching in a poststroke adult sample with time after stroke ranging between 4 and 63 months. As expected, some patients presented a smaller hand aperture during reaching of the glass, especially with cUL. In turn, patient 3 showed an aperture larger than normal, which may result of the difficulty in calibrating movement through internal feedback (characteristic of cerebellum dysfunction) (Bastian, 2008; Koziol et al., 2014). In most cases, the maximum hand aperture occurred earlier than normal and the beginning of deceleration as well, which may be related to the anticipation of difficulty in grasping the glass and / or to the fear of tipping it.

In T2, most patients improved these kinematic metrics in reaching, with the main exceptions of patients 1 and 3, that increased considerably their anterior trunk displacement and had excessive shoulder abduction especially in cUL. This UL of patient 1 also increased index of curvature, started the deceleration even earlier and opened hand even less.

In forward transporting, ensuring a correct hand trajectory becomes challenging because the force of gravity and inertia to overcome are higher than in reaching, due to the additional transport of the glass (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). In T1, patient 1 had decreased elbow flexion angle in the end of this phase, which may be explained for the difficulty in the recruitment of necessary motor units of elbow flexors to overcome this inertia. His excessive wrist radial deviation could be a strategy to compensate elbow impairment. In this phase is also necessary to ensure proper orientation of this object to avoid spilling water, and, perhaps even more challenging, the target for which the glass is transported, i.e. the mouth, is not visible (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). This increases the need to use proprioceptive information from the hand, UL and mouth to map the trajectory to be performed, to detriment of visual one (Maitra & Junkins, 2004; Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). This may explain the high index of curvature and the high NMU in most patients (in cUL), especially in T1. In T2, some of these alterations improved, with the main exceptions of NMU of patient 3, and the shoulder abduction of patients 1 and 3, that increased especially in cUL.

In typical drinking phase, the glass assumes an oblique orientation and the main purpose of the task is achieved. Perhaps for this reason, this is typically the slowest phase (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019). The relative duration of this phase was, in some patients, longer than normal, especially with iUL, which may reflect difficulty in modifying the components required for proper glass orientation. For this it is necessary shoulder flexion and abduction, forearm pronation, and wrist radial deviation and extension (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019), and patient 5, for example, had lower shoulder flexion and abduction of iUL. In Kim et al. study (2014), poststroke patients had lower flexion and greater abduction of shoulder, lower pronation of forearm and greater wrist flexion than controls, during this phase. It will be interesting for future studies to analyse glass orientation behavior especially in this phase to clarify if poststroke patients can obtain and keep a proper oblique orientation of the glass to drink a sip of water. In T2, it is noteworthy that patients 4 and 5 presented a high NMU bilaterally, and patients 3 and 4 had an excessive peak velocity of cUL during this phase, which may reflect difficulty in obtaining and keeping proper orientation of the glass.

In typical backward transporting, there is an increase in the distance between the hand and the axes of rotation of the elbow and shoulder in the sagittal plane, increasing, consequently, the torque required to produce movement. Moreover, this transport is mainly ensured by an eccentric contraction of the biceps, which is more demanding to control by CNS than a concentric one (Yao et al., 2017). In addition, center of mass moves away from the center of the base of support, reducing postural stability, which can compromise the quality of movement (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019; Shumway-Cook & Woollacott, 2017). Patient 3 seems to have presented special difficulty in this phase with both ULs in T1, but in T2 his performance worsened further, especially with cUL, taking longer time in this phase. Both ULs started deceleration earlier than expected and ended transport with excessive elbow flexion, which may reflect the difficulty when the distance between the hand and the axes of rotation increases. cUL had a very high NMU and index of curvature, and ended with excessive shoulder abduction. In addition, this patient had high anterior and ipsilateral displacement of the trunk, which may have been used to facilitate the movement and posture challenges (Mesquita, Fonseca, Borgonovo-Santos, Lima, et al., 2019).

Finally, after placing the glass on the table, in typical returning of DRINK task, it is necessary to release it to return to the starting position. Since this is generally a difficult movement for poststroke adults, we considered relevant to analyse the magnitude and the relative instant of the maximum hand aperture. Most patients had a smaller maximum aperture of at least one hand during returning. Also, some of them took longer to get the maximum hand aperture. After releasing the glass, this is probably the easiest path of the hand during DRINK task, since the target (the thigh) is the least demanding and in returning of LIGHT task, the trajectory is even easier (Mesquita, Fonseca, Borgonovo-Santos, Ribeiro, et al., 2019). Nevertheless, all types of kinematic alterations also occurred in this phase in both tasks.

4.1.2 Ipsilesional upper limb

Other studies (Bustren et al., 2017; Desrosiers et al., 1996; Metrot et al., 2013; Noskin et al., 2008; Nowak et al., 2007; Sunderland et al., 1999; van Dokkum et al., 2014; Wetter et al., 2005) have also reported ipsilesional motor deficits after stroke, including during DRINK (Bustren et al., 2017). However, in the study of Bustrén et al. (2017), kinematics has improved over time and reached a level comparable with controls at 3 months, except for those with more severe motor impairment (i.e. moderate motor impairment according to the FMA-UE – score between 32 and 57). In contrast, in our study, we found both moderate and mildly impaired patients had alterations in iUL in T2. Bustrén et al. (2017) also found that those patients who had moderate motor impairment had deficits that are more prominent in the iUL than those who had mild motor impairment. However, in this case series, this did not happen, since, for example, patient 1 (with mild impairment in T1 and T2) had more kinematic alterations in iUL than patient 5 (with moderate impairment in T1). The patient with most kinematic alterations in iUL in both moments was patient 3 (with the highest initial severity after stroke). Therefore, initial stroke severity (according to the NIHSS) may have been the factor with greatest impact on the extension of alterations in iUL. Regarding the type of kinematic alterations, in Bustrén et al. study (2017), movements of the iUL were slower, less smooth, with prolonged relative time in deceleration, and increased shoulder abduction. In our study, alterations in smoothness and duration of the deceleration period were also found; but, beyond slower velocity, we also found high mean and peak velocities in iUL, which may represent an impairment in the recruitment of the adequate number of motor units. In addition, we also found high index of curvature, alterations in hand aperture, shoulder, elbow and wrist angles in the various planes and excessive trunk displacement in the three planes.

Several bilateral neural mechanisms may justify the dysfunction of iUL. A dominant theory suggests that the ipsilesional uncrossed descending corticospinal pathways may explain this dysfunction, since approximately 10% to 15% of the corticospinal pathways run uncrossed through the spinal cord and therefore can also affect the function of the iUL (Shumway-Cook & Woollacott, 2017). Alternatively, a body of evidence (Favre et al., 2014; Grefkes & Fink, 2011; Shimizu et al., 2002; Ward & Cohen, 2004) supports that damage in one hemisphere also disturbs the neural processing between the hemispheres. Beyond this, both reticular and vestibular systems innervate body musculature ipsi- and contralaterally (Bassoe Gjelsvik & Syre, 2016). Therefore, a stroke affecting motor pathways on one side of the brain may result in reduced motor control on both sides (Silva et al., 2014).

4.2 Implications for stroke rehabilitation and future research

To our knowledge, this was the first study to: i) characterize patients and their stroke, according to SRRR recommendations (Kwakkel et al., 2017); ii) select two ADLs with different handling requirements; iii) normalize tasks environment to the anthropometric characteristics of each patient; and iv) analyse bilaterally "end-point kinematics" and "joint kinematics". This approach was intended to contribute to: i) the optimization of poststroke patients stratification; ii) the inclusion of patients with hand impairment; iii) the improvement of the experimental setup underlying the UL kinematic analysis; and iv) the implementation of bilateral kinematic assessment.

The assessed patients had some characteristics in common, such as to have an Iberian ethnicity and a premorbid function without alterations, but they also had many other different characteristics, such as initial stroke severity, age and stroke location, making it a heterogeneous group. Currently, initial stroke severity and patients' age are considered the strongest predictors of outcome after acute stroke (Kwakkel et al., 2017) and our results seem to corroborate this, since, in T2, patient 3 (with the highest initial stroke severity) had more kinematic alterations than the other patients and often the highest ones, and patient 4 (the oldest) was the only one who could not perform the DRINK task in T1. However, stroke location of patient 3 may have been determinant not only in the specificity of his deficits, but also in his motor recovery. His stroke damaged directly superior and middle cerebellar peduncles, which contain most of the cerebellar efferent fibers (to the thalamus and then to the cortex) and the fibers from the pontocerebellar tract (with information from sensory, motor, premotor, and posterior parietal cortex), respectively (Lundy-Ekman, 2012; Shumway-Cook & Woollacott, 2017). These fibers allow the connection between the cortex and the cerebellum, namely its lateral hemispheres, often called cerebrocerebellum. This area participates in programming the motor cortex, specifically for the correct timing of muscle activity (motor coordination), by refined control of the interplay between the activity of agonists and antagonists muscles. Impairment of this control usually manifests in dysmetria, terminal tremor, and dysdiadokokinesia (Lundy-Ekman, 2012). Therefore, high index of curvature and NMU, as well as the change in the duration of the acceleration (by agonists) vs deceleration periods (by antagonists), more significant in this patient, may be explained by the impairment of the fibers connect to cerebrocerebellum. The inaccurate movement could also result of another function of this area. Cerebrocerebellum is also involved in the evaluation of sensory information for action as a part of the motor learning process, acquiring and storing internal models (models of all of the sensory and motor information required for performance of any specific activity) (Koziol et al., 2014). These internal models are adjusted and refined as behavior is repeated through learning process and because of them, the motor cortex is able to perform an accurate movement using an internal feedback instead of the external feedback from actual behavior, overcoming the time delays associated with sensory feedback (Bassoe Gjelsvik & Syre, 2016). Therefore, the impairment of this internal feedback could result in inaccurate movements. Deficits in motor learning also complicates improvement via rehabilitation training since patients with cerebellar dysfunction often do not store the effect of short-term training (Bassoe Gjelsvik & Syre, 2016). This may explain the exacerbation of some kinematics of patient 3 in T2. Thus, can a cerebellar infarction be associated with poorer motor recovery of the UL than other stroke location? To our knowledge, studies that have so far looked at the effect of stroke location on motor recovery (Cheng et al., 2014; Feys, Hetebrij, Wilms, Dom, & De Weerdt, 2000; O. Wu et al., 2015) have not included strokes that damage the cerebellum. Future studies should try to clarify this issue. The contribution of other factors that were not so evident in this case series should also be explored in future studies with a higher number of patients, such as stroke side, presence of comorbidities, thrombolysis/reperfusion therapy, and physical therapy interventions. Patient 1 was the only one who did not perform physiotherapy and one of those who presented more bilateral kinematic changes and compensatory strategies. In addition, like patient 4, patient 1 had diabetes – a comorbid condition that have also been associated with poorer stroke recovery (Kwakkel et al., 2017).

To include patients with hand impairment (according to FMA-UE), beyond the DRINK task, we selected the LIGHT task whose interaction with the switch seems to be easier. To avoid frustration and consequent interference with the tasks performance, as a decision criterion for performing the DRINK with the cUL, we defined a minimum score of 8 in the "Hand" section of the FMA-UE, corresponding to more than 50% of the maximum score (14). This section assesses the ability to perform full fingers flexion and extension and a variety of different grip types. In the group of patients evaluated, only patient 4 had a score lower than 8 in the referred section and, therefore, only his exclusion was avoided. However, in future studies, selection of simpler ADLs, such as LIGHT task, may contribute to decrease the exclusion of several adults, making it possible to increase sample sizes.

Normalization of experimental setup to the anthropometric characteristics of each individual is important to ensure that it is not the responsible for variability in the kinematic metrics analysed. Both variations in the adopted position and the location of the target can create this variability, therefore it is important that future studies do their normalization.

Recognizing the impact of a unilateral stroke on both ULs is an important step towards implementing effective rehabilitation (Kitsos et al., 2013), but also effective clinical evaluation (Bustren et al., 2017). If iUL is used as a reference in several clinical assessments, such as FMA-UE, this means that the scores of cUL may be underestimated (Bustren et al., 2017). Therefore, it is important to update the clinical assessment to consider bilateral impairment and to use data from healthy adults as reference. Further studies with healthy adults are needed to make these references progressively more robust.

The identification of the kinematics that best identify UL dysfunction to reliably evaluate motor function and treatment efficacy after stroke is challenging (Murphy et al., 2011), but necessary (Kwakkel et al., 2017). For this, it is important to recognize that the impairment of specific CNS regions with particular functions in the UL sensorimotor control may determine the type of kinematics affected. On the other hand, it is important to analyse different motor skills and clarify the interpretation of kinematics, excluding from the core set those that may be explained by others and therefore become redundant.

Finally, it is essential to assess the validity of trunk displacement as compensation metric. To our knowledge, to date, this metric has been included in UL kinematic studies only as a measure of compensation for impaired UL mobility, and not as a motor impairment directly caused by stroke that may, consequently, affect UL function. However, excessive trunk displacement may result of dysfunction of areas such as pontomedullary reticular formation (PMRF). PMRF receives signals coming from cortical and sub-cortical structures related to preparatory anticipatory postural adjustments (pAPAs) and accompanying postural adjustments (aAPAs), and integrate them into a unified descending command signal to control posture and movement (Yakovenko & Drew, 2009). Proximal trunk stability provides the foundation for efficient functioning of the ULs (Raine et al., 2009), so the distal changes observed in some patients (such as patient 3 who had a stroke that damaged directly the pons) may result from the inability to maintain trunk stability through the postural adjustments mentioned above. Future studies should associate electromyography with kinematic and analyse this possibility. On the other hand, other compensatory strategies, such as increased shoulder abduction (Massie, Malcolm, Greene, & Thaut, 2009) should be considered in future studies.

4.3 Limitations

One of the limitations of this study was the small number of cases, which was mainly conditioned by the location of the kinematic assessments (laboratory). This excluded eighteen patients who, after discharge, were transferred to a rehabilitation unit. Future studies should validate portable systems to allow kinematic analysis in a clinical context. Another limitation was that the healthy reference used did not have appropriate age and BMI categories for patient 4 (> 75 years old and obesity, respectively), so the identification of kinematic alterations in the variables influenced by age and BMI may be incorrect in this patient.

5. Conclusion

In this case series, both ULs of five poststroke adults were kinematically analysed in the early subacute phase and in the beginning of chronic phase. To our knowledge, this was the first study to apply SRRR recommendations for patient and stroke information collection; to select two ADLs with different handling requirement; and to analyse a comprehensive set of end-point and joint kinematics bilaterally. Differences were found between the kinematic strategies used by poststroke adults to perform DRINK and LIGHT tasks and those of previously studied healthy adults. All patients presented kinematic alterations in both ULs, in both moments, although, in most cases, the differences were more subtle in the iUL and their extent have decreased from early subacute phase to the beginning of chronic phase. These results support the implementation of bilateral assessments to fully study motor impairment post stroke.

Future studies should analyse the impact of factors such as stroke location, as it seems to influence the specificity of alterations and the recovery, as well as clarify the interpretation of kinematic metrics and identify a core set of kinematics that best recognize UL dysfunction after stroke.

6. Conflict of Interest Statement

The Authors report no conflicts of interest.

5. GENERAL DISCUSSION

The findings obtained in the studies presented in the previous chapters have contributed to the achievement of the purposes stated for this thesis. Specifically, the findings have contributed to the understanding of: (i) the kinematic strategies used by healthy adults during drinking task; (ii) the differences between kinematic strategies used by healthy adults in two ADLs with different handling requirement: drinking and turning on the light tasks; (iii) the kinematic strategies used by poststroke adults during the same ADLs and the differences between them and those of healthy adults.

Through our systematic review, we aimed to review the methods used to analyse the kinematic of ULs of healthy and poststroke adults, namely specificities of sampling and motor tasks (article I) and motion capture systems and kinematic metrics (article II). For this purpose, we have considered all articles that had the purpose to analyse objectively 3D kinematic of ULs, studied clearly described functional movements of ULs, or ADL involving ULs, and studied healthy living adult humans and/or adult humans with stroke sequelae. Although this review does not answer directly to the objectives of the thesis, it gave us the necessary knowledge regarding the methods limitations of previous studies and the needs for future studies, contributing greatly to improve methodological approach of our observational studies. Indeed, it became clear the need to: i) study older healthy adults, to understand if kinematic metrics are affected by aging and, accordingly, to obtain typical movement data that consider this factor; ii) analyse more healthy women; iii) consider the presence of chronic diseases and factors, such as the social, lifestyle and physical ones, in inclusion/exclusion criteria and in the characterization of participants; iv) improve stroke characterization; v) get poststroke kinematic data without significant variation in the time poststroke onset between patients; vi) study real ADLs to analyse natural movement of participants; vii) explore other motor skills beyond reaching, like transporting and hand aperture to grasp or release; viii) analyse ADLs with less handling requirements to enable the assessment of poststroke patients with hand impairment; ix) obtain kinematic data of the dominant and non-dominant ULs of healthy adults and of the contralesional and ipsilesional ULs of poststroke adults; x) use optoelectronic systems (considered the gold standard for kinematic analysis) and presented laboratory and task-specific errors; xi) normalize the experimental setup to anthropometric characteristics of participants; and, finally, xii) select a wide set of end-point and joint kinematics to quantify different movement characteristics.

In our first two observational studies (articles III and IV), we improved the inclusion/exclusion criteria of healthy adults and it was possible to study a healthy sample with a broad age range (30-69 years) in which 60% were women and 40% were men. All participants were right-handed, had a BMI between 18.5 and 30.0 and had an insufficient physical activity level. In addition, they had no current or previous history of pathology, surgery, or pain that could affect ULs function, and were not pregnant. In article III we studied a real ADL, namely drinking task, performed by dominant and non-dominant ULs, and we explored most of its motor skills divided by its five phases: reach and hand aperture to grasp the glass, in "reaching" phase; concentric transport of glass towards a non-visible target (mouth), whose efficiency is more dependent on proprioceptive information than on visual one, in "forward transporting" phase; changing the vertical orientation of the glass to an oblique orientation to accomplish the purpose of the task, in drinking phase; eccentric transport of the glass towards the table (more posturally demanding), in "backward" transporting phase; and hand aperture to release it and returning to the starting position, in "returning" phase. Furthermore, we used the gold standard system for kinematic analysis – an optoelectronic system – and presented laboratory and task-specific errors; we normalized experimental setup (seat height, length of thigh in contact with the seat, and location of the table and glass) to anthropometric characteristics of each participant; and we selected a wide set of end-point and joint kinematics to quantify speed, control strategy, efficiency, smoothness, hand aperture, functional multi-joint angles and compensation. This study was groundbreaking because, to the best of our knowledge, no other study about drinking analysed: a) this set of kinematic metrics in all phases of the task; b) the hand aperture; c) the joint angles of the shoulder, elbow and wrist in the phases transitions; d) and trunk displacement in frontal and transverse planes. In addition, no other study normalized the base of support and the glass location to the anthropometric characteristics of each participant. Thus, it was possible to obtain a reliable and comprehensive analysis of the kinematic strategies used by healthy adults during drinking task and answer directly to the first specific objective of this thesis. However, to improve understanding of the UL motor performance during other ADLs and enable their assessment in poststroke patients with hand impairment, it was necessary to select other ADL with less handling requirement in this same sample, which led us to the following study (article IV).

In our second observational study (article IV), we aimed to answer to our second specific objective. For this, we chose an ADL involving reaching and touching a target (switch) without having to grasp it, transport it or release it – turning on the light – and compared the kinematic strategies used by the ULs of healthy adults in this ADL with those used in drinking. Although the interaction with the target is clearly different, these two tasks have two common gestures, which made them comparable: i) reaching an object and ii) returning to the starting position. Therefore, the procedures for experimental setup, data processing and analysis were similar to those of the previous article (III). We found that the different target formats and the different interaction of these two tasks seem to be responsible for differences in speed profile, efficiency, smoothness, as well as joint angles and trunk displacement. These results support the concept that movement varies according to the purpose and constraints of the task (Shumway-Cook & Woollacott, 2017), and highlight the need to explore more ADLs in order to achieve a comprehensive assessment of quality of motor ULs performance after stroke. No other study about kinematic analysis of the ULs, as far as we know, analysed turning on the light, studied an ADL with less demanding handling and compared two ADLs with different handling requirements. Therefore, this article was innovative and launched the challenge to analyse more ADLs.

Moreover, in both articles in which we evaluated healthy adults (articles III and IV), we analysed the influence of age, sex, dominance and BMI in the kinematic strategies used and we found that age and sex were the main factors exerting effect on some of the kinematics analysed, namely those related to speed, efficiency, smoothness, hand aperture, joint angles and compensation. These results emphasised the need to consider these factors in kinematic analysis of ULs of healthy and poststroke adults. Accordingly, if motor performance of these ADLs was influenced by factors such as age and sex, the healthy reference used for poststroke adults should consider the variations produced by these factors and be adjusted according to the specific characteristics of the assessed patients. This was exactly what we did in the last study of this thesis (article V).

The analysis of the kinematic strategies used by the healthy adults in articles III and IV served as the basis for the analysis of the ULs of poststroke adults (article V). In our fifth article, we studied the kinematic strategies of both ULs of poststroke adults in the early sub-acute phase and in the beginning of chronic phase and compared them with the strategies used by the healthy. Considering the need to improve the characterization of patients and their strokes, as well as the need to analyse their kinematic strategies according to their specific characteristics, we selected the most appropriate type of study for this purpose: a case series. Since stroke includes a set of heterogeneous clinical conditions, the implementation of this type of study seems to ease the understanding of this heterogeneity and, consequently, optimize stratification. As we chose to implement kinematic analysis in two key moments of stroke recovery, where patients are often in rehabilitation units, and we opted for an optoelectronic motion acquisition system that could not be transported to these units, this limited the number of patients assessed. Nevertheless, this study pioneered: i) the characterization of patients and their strokes according to SRRR recommendations (Kwakkel et al., 2017); ii) the kinematic analysis of an ADL with less handling requirement and, consequently, the inclusion of poststroke adults with greater sensorimotor impairment of the hand; iii) the bilateral kinematic assessment; iv) the normalization of experimental setup to anthropometric characteristics of participants; and v) the selection of a wide set of end-point and joint kinematics to quantify diverse movement characteristics of different motor skills (beyond reaching).

Characterization according to SRRR aimed to understand the contribution of multiple factors in UL recovery. In our case series, initial severity of stroke and patients' age seem to have been the most important factors to explain the extent of kinematic alterations, which corroborate the consideration of these two factors as strongest predictors of outcome after acute stroke (Kwakkel et al., 2017). However, stroke location seems to have influenced the specificity of the deficits as well as the recovery and little attention has been given to this factor in kinematic analysis. Moreover, to our knowledge, studies that have so far looked at the effect of stroke location on motor recovery (Cheng et al., 2014; Feys et al., 2000; O. Wu et al., 2015) have not included strokes that affected the brainstem or cerebellum, which limits their conclusions to brain injury. Since ischaemic or haemorrhagic injury to these structures can also cause motor impairment (Warlow et al., 2008), future studies should explore the role of stroke location in specificity of deficits and motor recovery. The contribution of other factors that was not so evident in this case series should also be explored in future studies with a higher number of patients, such as stroke side, presence of comorbidities, thrombolysis/reperfusion therapy, physical therapy interventions, among others. In the dominant left hemisphere (for skilled movement), processing of sensory-motor data is dependent on a more widespread and more densely connected network (Guye et al., 2003), where damage to one component is more easily replaced by other network components (though, such replacement is not expected for large lesions affecting multiple networks) (Frenkel-Toledo et al., 2019). Therefore, left hemisphere may take some advantage for recovery processes (Frenkel-Toledo et al., 2019). Some comorbid conditions have also been associated with poorer stroke recovery, e.g. diabetes (Kwakkel et al., 2017). An overwhelming number of studies and clinical trials confirm the efficacy of thrombolytic therapy, in a given therapeutic window, in improving the clinical outcome and recovery of acute ischemic stroke patients (Hacke et al., 2004; Kwiatkowski et al., 1999; Lees et al., 2010). Regarding physiotherapy intervention, it was not the objective of this study to analyse the type of procedures, frequency and intensity, but naturally these may have influenced the recovery of participants and the restitution of original motor patterns vs.

development of compensatory strategies. Futures studies should define more clearly the interventions that carry benefit, and to quantify that benefit in a routine clinical setting (Peter Langhorne et al., 2009).

We selected two ADLs with different levels of difficulty to include patients with hand impairment and LIGHT task seems to be an ADL that patients with hand impairment can accomplish. To avoid frustration and consequent interference with the tasks performance, as a decision criterion for performing drinking task with the cUL, we defined a minimum score of 8 in the "Hand" section of the FMA-UE, corresponding to more than 50% of the maximum score (14). In the group of patients evaluated, only one patient had a score lower than 8 in the referred section and, therefore, only his exclusion from the study was avoided. However, future selection of simpler ADLs, such as turning on the light task, in studies analysing UL kinematic, may contribute to decrease the exclusion of several adults with greater distal impairment, making it possible to increase sample sizes.

In our study, all patients had iUL alterations in at least one kinematic metric and, in most cases, in both tasks. Recognizing the impact of a unilateral stroke on both ULs is an important step towards implementing effective rehabilitation (Kitsos et al., 2013), but also effective clinical evaluation (Bustren et al., 2017). If iUL is used as a reference in several clinical assessments, such as FMA-UE, this means that the scores of the cUL may be underestimated (Bustren et al., 2017). Therefore, it is important to update the clinical assessment to consider bilateral impairment and to use data from healthy adults as reference. This update will also allow the inclusion of adults who have one or more strokes that affect the CNS bilaterally. This factor highlights the importance of building increasingly robust healthy adult databases.

All the kinematic metrics analysed presented alterations in the assessed patients. Although most of these changes were in the expected direction, such as less smoothness of movement, greater trunk displacement, etc., in some patients, some variables showed values that were not expected, i.e., apparently "better" than those of the healthy reference, namely duration, velocity and index of curvature. Future studies will need to clarify whether shorter duration, higher speed and lower index of curvature than healthy reference may be associated with quality motor performance, or may be related to poor motor control of the ULs and consequently with poor motor performance. Therefore, the identification of the kinematics that best identify UL dysfunction to reliably evaluate motor function and treatment efficacy in poststroke adults is necessary (Kwakkel et al., 2017). For this, it is important to recognize that the impairment of specific CNS areas with particular functions in the UL sensorimotor control may determine the type of kinematics affected. On the other hand, it is important to analyse different motor skills and explore the correlation between kinematics and how they may explain each other. The correlation between joint kinematics, for example, may reflect the existence of atypical flexor or extensor muscle synergies, which may, in turn, be related to the stroke location. In addition, it is important to consider the exclusion from the core set of kinematics, those that are explained by others and therefore become redundant information.

Finally, it is essential to assess the validity of trunk displacement as compensation metric. To our knowledge, to date, trunk displacement analysis has been included in UL kinematic studies only as a measure of compensation for impaired UL mobility, and not as a measure of motor impairment directly caused by stroke that may, consequently, affect UL function. Future studies should consider this possibility and associate electromyographic analysis with kinematic analysis. Probably, if excessive displacement of trunk is indeed compensation for decreased UL mobility, postural adjustments will remain intact. On the other hand, other compensatory strategies, such as increased shoulder abduction (Massie et al., 2009) and radial deviation of wrist, should be considered in future studies.

6. CONCLUSIONS AND FUTURE WORK PERSPECTIVES

The complex motor recovery of ULs after stroke and the need to optimize the assessment of motor performance quality after stroke, through kinematic analysis, were the trigger for the elaboration of this thesis. In our systematic review of literature, we found some gaps in the used methods, namely in sampling, selected motor tasks, motion capture systems and kinematic metrics. The identification of these limitations allowed us to improve the methods used in our observational studies, in which we intend to meet the specific objectives of the thesis.

The results of our observational studies allowed us to answer directly to our three objectives outlined in the thesis. First, a comprehensive kinematic characterization of the drinking task performed by healthy adults was made and end-point and joint kinematics analysis allowed the identification of the different kinematic strategies used in each phase of the task with their specific motor skills. In addition, it was found that age and sex had significant effects on some of the kinematics analysed, particularly those related to speed, hand aperture, joint angles and compensation. Second, a comparison of the kinematic strategies used by healthy adults in an ADL with less demanding handling (turning on the light) with those that are used in drinking task was made. In addition, it was found that age and sex had significant effects on some of the kinematics analysed, particularly in turning on the light task. Third, both ULs of five poststroke adults were kinematically analysed in the early subacute phase and at the beginning of chronic phase and differences were found between the kinematic strategies used by poststroke adults to perform drinking and turning on the light tasks and those of previously studied healthy adults; all patients presented kinematic alterations in both ULs, in both moments, although, in most cases, the differences were more subtle in the iUL and their extent have decreased from early subacute phase to the beginning of chronic phase.

The findings obtained in the studies of this thesis have contributed to the improvement of the scientific knowledge about ULs movement of healthy and poststroke adults during the performance of ADLs, namely drinking and turning on the light tasks. Specifically, the findings obtained have contributed to: (i) improve methodological approach for kinematic analysis of both ULs in healthy and poststroke adults; (ii) get a healthy reference of the quality of ULs motor performance in two ADLs; and (iii) understand and differentiate the kinematic strategies used by healthy and poststroke adults, during two ADLs with different motor skills and handling requirements. However, much remains to be done to optimize the assessment of quality of ULs motor performance. It is necessary to: analyse more ADLs, namely the interaction with different objects of daily life, to gain a deeper understanding of ULs movement; clarify the interpretation of some kinematic measures, such as trunk displacement as compensation measure vs. measure of decreased postural control; study the relation and redundancy between kinematic variables in order to define a key set of kinematic metrics; study more healthy adults, with >70 years old, higher levels of physical activity, etc., to build robust healthy databases and understand if level of physical activity interferes with the movement pattern; study more poststroke patients with different stroke characteristics, such as stroke location, and explore its influence on motor performance and motor recovery; and develop and validate portable and accurate motion acquisition systems to allow the assessment of poststroke patients in hospital and clinical settings.

7. RELEVANT CONTRIBUTIONS TO OTHER SCIENTIFIC PROJECTS

Currently, our methodological approach for kinematic analysis of ULs and assessment of quality of their motor performance was adopted by two ongoing scientific projects: the “FES-ABLE/FES-HAND” and the “Kinematic evaluation in upper limb neurofunctional rehabilitation in patients with chronic stroke” projects.

The FES-ABLE project results from an Iberian partnership between the Center for Rehabilitation Research (CIR) and the highest technological center of Europe, Tecnália, and is being funded by “Fundación General CSIC” (C.I.R., 2018). This project aims to evaluate the impact of an intervention based on a multichannel functional eletrical stimulation (FES) prototype on the UL movement quality during functional tasks and its results will contribute to the definition of the therapeutic window of FES to improve UL function in stroke rehabilitation. In addition to this project being using the methodological approach proposed in this thesis (regarding the motor tasks analysed, movement acquisition system used and kinematic measures studied), the kinematic data of our healthy adults are being used as reference for the expected movement.

The “Kinematic evaluation in upper limb neurofunctional rehabilitation in patients with chronic stroke” project is being developed as part of a doctoral project of Fellipe Bandeira Lima – Ph.D. student in Physiotherapy at Faculty of Sports of University of Porto (FADEUP). This project aims to compare upper limb movements before and after neurofunctional rehabilitation in poststroke patients with chronic phase. The research is taking place in the Laboratory of Biomechanics and Motor Behavior of the State University of Maringá, Paraná, Brazil.

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APPENDIX I – Ethical approval

U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

Ethics Committee

ETHICS OPINION

Process **CEFADE 08.2016**

The Ethics Committee of the Faculty of Sport from the University of Porto analyzed the project entitled "Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico" presented by MSc. Inês Albuquerque Mesquita. Considering the project's characteristics, as well as the competence of the research team, the Ethics Committee addresses a positive opinion, because the ethical principles that govern this type of scientific work are respected.

Porto and Faculty of Sport, 7th March, 2016

The chairman of the Ethics Committee,

José Alberto Ramos Duarte

Figure 1 - Ethical approval of CEFADE

centro hospitalar
do Porto

Hospital de Santo António Maternidade Júlio Dinis Hospital Maria Pia

Largo Professor Abel Salazar
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COMISSÃO DE ÉTICA PARA A SAÚDE

APRECIAÇÃO E VOTAÇÃO DO PARECER

Deliberação	Data: 26.10.2016	Órgão: Reunião Plenária

Título: **"Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico"**	Ref.ª: **2016.161(135-DEFI/126-CES)**

Protocolo/Versão: **TA - DT**	Promotor: **o(a) próprio(a)**	Investigador: **Inês Albuquerque Mesquita** **Licenciada em Fisioterapia, Aluna do 2º Ano do Doutoramento em Fisioterapia da Faculdade de Desporto da Universidade do Porto**

A Comissão de Ética para a Saúde – CES do CHP, ao abrigo do disposto no Decreto-Lei n.º 97/95, de 10 de Maio, em reunião realizada nesta data, apreciou a fundamentação do relator sobre o pedido de parecer para a realização de **TA - DT** acima referenciado:

Ouvido o Relator, o processo foi votado pelos Membros da CES presentes:

Presidente: Dr.ª Luisa Bernardo
Vice-Presidente: Dr.ª Paulina Aguiar

Dr.ª Fernanda Manuela, Enf.ª Paula Duarte, Prof.ª Doutora Carla Teixeira, Prof.ª Doutora Maria Manuel Araújo Jorge, Dr. Gonçalo Senhorães Senra.
Resultado da votação:

PARECER FAVORÁVEL

AUTORIZADO
Dr. Severo Torres
Adjunto do Diretor Clínico
Data: 21/11/16

A deliberação foi aprovada por unanimidade.

Pelo que se submete à consideração superior.

Data 26.10.2016

A Presidente da CES

Dr.ª Luisa Bernardo

Imp.10/2009

Figure 2 - Ethical approval of Centro Hospitalar do Porto

Unidade Local de Saúde de Matosinhos Hospital Pedro Hispano	Informação	Nº 57/CE/JAS Data: 16-09-2016

Para: **Serviço de Gestão do Conhecimento**
De: Comissão de Ética

Assunto: **Pedido de autorização para realização de estudo intitulado" Caracterização do movimento do membro superior e tronco de indivíduos com sequelas de acidente vascular encefálico"**

Informação

Exmos. Senhores,

A Comissão de Ética analisou o pedido de autorização para realização de estudo intitulado "**Caracterização do movimento do membro superior e tronco de indivíduos com sequelas de acidente vascular encefálico**", proponente a aluna Inês Albuquerque Mesquita no âmbito do Doutoramento em Fisioterapia da Faculdade de Desporto da Universidade do Porto.

Decidido nada opor à realização deste estudo, desde que:

1 – O recrutamento dos participantes, seja efectuado por um profissional da equipa que trata o doente.

2 – Seja solicitado parecer da C.N.P.D.

Com os melhores cumprimentos,

Dr. José Alberto Silva
Presidente da Comissão de Ética
da ULSM Matosinhos

Dr. José Alberto Silva
(Presidente da Comissão de Ética da U. L. S. – Matosinhos)

001_01_INF_1260 Unidade Local de Saúde de Matosinhos

Figure 3 - Ethical approval of U. L. S. - Matosinhos

Autorização n.º 12852/ 2016

Inês Albuquerque Mesquita notificou à Comissão Nacional de Protecção de Dados (CNPD) um tratamento de dados pessoais com a finalidade de realizar um Estudo Clínico sem Intervenção, denominado Caracterização do movimento do membro superior e tronco de indivíduos com sequelas de acidente vascular encefálico .

A investigação é multicêntrica, decorrendo, em Portugal, nos centros de investigação identificados na notificação.

O participante é identificado por um código especificamente criado para este estudo, constituído de modo a não permitir a imediata identificação do titular dos dados; designadamente, não são utilizados códigos que coincidam com os números de identificação, iniciais do nome, data de nascimento, número de telefone, ou resultem de uma composição simples desse tipo de dados. A chave da codificação só é conhecida do(s) investigador(es).

É recolhido o consentimento expresso do participante ou do seu representante legal.

A informação é recolhida diretamente do titular e indiretamente do processo clínico.

As eventuais transmissões de informação são efetuadas por referência ao código do participante, sendo, nessa medida, anónimas para o destinatário.

A CNPD já se pronunciou na Deliberação n.º 1704/2015 sobre o enquadramento legal, os fundamentos de legitimidade, os princípios aplicáveis para o correto cumprimento da Lei n.º 67/98, de 26 de outubro, alterada pela Lei n.º 103/2015, de 24 de agosto, doravante LPD, bem como sobre as condições e limites aplicáveis ao tratamento de dados efetuados para a finalidade de investigação clínica.

No caso em apreço, o tratamento objeto da notificação enquadra-se no âmbito daquela deliberação e o responsável declara expressamente que cumpre os limites e condições aplicáveis por força da LPD e da Lei n.º 21/2014, de 16 de abril, alterada pela Lei n.º 73/2015, de 27 de junho – Lei da Investigação Clínica –, explicitados na Deliberação n.º 1704/2015.

O fundamento de legitimidade é o consentimento do titular.

Figure 4 - Approval of Comissão Nacional de Proteção de Dados (continued)

Proc. n.º 18974/ 2016 | 2

A informação tratada é recolhida de forma lícita, para finalidade determinada, explícita e legitima e não é excessiva – cf. alíneas a), b) e c) do n.º 1 do artigo 5.º da LPD.

Assim, nos termos das disposições conjugadas do n.º 2 do artigo 7.º, da alínea a) do n.º 1 do artigo 28.º e do artigo 30.º da LPD, bem como do n.º 3 do artigo 1.º e do n.º 9 do artigo 16.º ambos da Lei de Investigação Clínica, com as condições e limites explicitados na Deliberação da CNPD n.º 1704/2015, que aqui se dão por reproduzidos, autoriza-se o presente tratamento de dados pessoais nos seguintes termos:

Responsável – Inês Albuquerque Mesquita

Finalidade – Estudo Clínico sem Intervenção, denominado Caracterização do movimento do membro superior e tronco de indivíduos com sequelas de acidente vascular encefálico

Categoria de dados pessoais tratados – Código do participante; idade/data de nascimento; género; dados antropométricos; dados da história clínica; dados dados de exame físico; dados de meios complementares de diagnóstico; medicação prévia concomitante

Exercício do direito de acesso – Através dos investigadores, presencialmente

Comunicações, interconexões e fluxos transfronteiriços de dados pessoais identificáveis no destinatário – Não existem

Prazo máximo de conservação dos dados – A chave que produziu o código que permite a identificação indireta do titular dos dados deve ser eliminada 5 anos após o fim do estudo.

Da LPD e da Lei de Investigação Clínica, nos termos e condições fixados na presente Autorização e desenvolvidos na Deliberação da CNPD n.º 1704/2015, resultam obrigações que o responsável tem de cumprir. Destas deve dar conhecimento a todos os que intervenham no tratamento de dados pessoais.

Lisboa, 06-12-2016

A Presidente

Filipa Calvão

Figure 4 - Approval of Comissão Nacional de Proteção de Dados.

SÃO JOÃO

Parecer da Comissão de Ética para a Saúde do

Centro Hospitalar de São João / Faculdade de Medicina da Universidade do Porto

Título do Projecto: Caracterização do movimento dos membros superiores e tronco dos indivíduos sem patologia e de indivíduos com sequelas de acidente vascular cerebral.

Nome da Investigadora Principal: Dra. Inês Albuquerque Mesquita

Serviço onde decorre o Estudo: Serviço de Neurologia do Centro Hospitalar de S. João. Apresentou declaração da Directora de Serviço, Prof.ª Doutora Carolina Garrett. O Dr. Pedro Castro, médico do Serviço de Neurologia, será o profissional de ligação.

Objectivos do Estudo: Esta investigação tem como objectivo caracterizar o movimento dos membros superiores e tronco de indivíduos sem patologia e indivíduos com sequelas de AVC (isquémico ou hemorrágico), durante o desempenho de duas tarefas funcionais (beber água de um copo e acender um candeeiro), na fase imediatamente após a alta hospitalar e no início da fase crónica, através da análise cinemática. No CHSJ, pretende-se apenas recrutar indivíduos com sequelas de AVC que preencham os critérios de inclusão para que, após a alta hospitalar e no início da fase crónica, possam ser avaliados no Laboratório de Biomecânica da Universidade do Porto.
Insere-se no âmbito do Doutoramento em Fisioterapia da FADEUP, sob orientação da Prof.ª Doutora Cláudia Silva e co-orientação da Prof.ª Doutora Ana Rita Pinheiro e do Prof. Doutor Miguel Velhote Correia.

Concepção e Pertinência do estudo: Para o efeito, aos doentes com AVC que preencham os critérios de inclusão será solicitada a realização de tarefas funcionais simples, designadamente beber água de um copo e acender um candeeiro, e serão realizados questionários devidamente anonimizados, dos quais se anexam as respetivas cópias. O recrutamento de doentes vulneráveis com AVC pode justificar-se pela natureza do estudo que se destina especificamente a avaliar esta população, sendo de antecipar que os participantes possam vir a beneficiar com a sua inclusão no estudo, face aos objectivos previstos (ver benefício/risco).

Benefício/risco: Os indivíduos com sequelas de AVC beneficiarão do incentivo da realização das tarefas funcionais avaliadas - tarefas fundamentais no seu dia-a-dia – potenciando a sua confiança na concretização destas e de outras tarefas. Não estão previstos incómodos ou riscos associados com o estudo.

Confidencialidade dos dados: A informação de contacto e historial de participação dos participantes será colocada numa base de dados segura, protegida por uma palavra-passe e que só pode ser acedida pelos

Figure 5 – Ethical approval of Centro Hospitalar de São João (continued)

investigadores deste projeto de investigação. A identificação dos indivíduos será codificada, sendo atribuído um número a cada um.

Respeito pela liberdade e autonomia do sujeito de ensaio: Está prevista a obtenção de consentimento informado, que é acompanhado de uma informação para o participante, esclarecedora sobre a natureza do estudo e que contempla as questões éticas relevantes.

***Curriculum* da investigadora**: Adequado à investigação.

Data previsível da conclusão do estudo: Julho de 2018.

Conclusão: Proponho um parecer favorável à realização deste projecto de investigação.

Porto, 17 de Fevereiro de 2017

O Relator da CES, Prof. Doutor Manuel Pestana

Figure 5 – Ethical approval of Centro Hospitalar de São João

APPENDIX II – Informed consent form

Doutoramento em Fisioterapia - Inês Albuquerque Mesquita

Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico

U.PORTO FACULDADE DE DESPORTO UNIVERSIDADE DO PORTO

OBJETIVOS DO PROJETO DE INVESTIGAÇÃO

Este projeto de investigação integra-se no Doutoramento em Fisioterapia, sob a orientação da Prof. Dra. Cláudia Silva e co-orientação da Prof. Dra. Ana Rita Pinheiro e Prof. Dr. Miguel Velhote Correia.

O objetivo principal é caracterizar o movimento do membro superior, através da análise de variáveis cinemáticas (do movimento), durante o desempenho das tarefas "acender a luz" e "beber água de um copo", permitindo assim o conhecimento e desenvolvimento de estratégias de reabilitação e aprendizagem motora que promovam a restituição do movimento do membro superior de indivíduos com sequelas de acidente vascular encefálico (AVE).

RECOLHA DE DADOS

Para analisar as variáveis cinemáticas, será necessário registar o movimento dos braços e tronco através de sensores. Os sensores serão colocados nos seus braços e tronco por técnicos especializados. Além disso, serão medidos o comprimento dos seus braços, tronco e pernas, para ajuste da localização dos objetos envolvidos nas tarefas. Ser-lhe-á pedido que realize três ensaios das tarefas mencionadas com os dois membros superiores, separadamente. A realização das tarefas será acompanhada pelos mesmos técnicos. O tempo total de preparação e recolha de dados estimado é de 1 hora. Poderão ser captadas algumas fotografias, apenas para registo da posição postural e interpretação de dados.

RISCOS

Não há riscos.

BENEFÍCIOS

Os dados recolhidos permitirão o conhecimento e desenvolvimento de ferramentas e estratégias a serem usadas nos processos de reabilitação e aprendizagem motoras dos membros superiores e tronco de indivíduos com sequelas de AVE.

Os indivíduos com sequelas de AVE beneficiarão do incentivo da realização das tarefas funcionais avaliadas - tarefas fundamentais no seu dia a dia – potenciando a sua confiança na concretização destas e de outras tarefas.

GARANTIA DE CONFIDENCIALIDADE

A informação recolhida será colocada numa base de dados segura, protegida por uma palavra-passe e que só pode ser acedida pelos investigadores deste projeto de investigação. Será garantido o anonimato.

Figure 1. Study information delivered to healthy participants (continued)

COMPENSAÇÃO

Não existem compensações financeiras por participar neste estudo. Será feito reembolso das despesas de transporte, sempre que se justifique.

PARTICIPAÇÃO

A sua participação é voluntária. Pode desistir sem penalização ou perca de benefícios a que possa ter direito, em qualquer momento. Se desistir do estudo antes que a aquisição de dados esteja concluída, os dados serão destruídos ou devolvidos. A recusa em participar ou posterior abandono, não prejudicarão a sua relação com a equipa de clínicos ou investigadores.

CONTACTO

Se tiver alguma dúvida ou questão sobre o projeto de investigação, pode contactar o investigador responsável, Inês Mesquita, através do email ou telemóvel (inesamesquita@gmail.com ou 962469291).

MUITO OBRIGADA PELA SUA COLABORAÇÃO!

Página 2

Figure 1 - Study information delivered to healthy participants.

Doutoramento em Fisioterapia - Inês Albuquerque Mesquita

Caracterização do movimento dos membros superiores e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular cerebral

U.PORTO
FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

OBJETIVOS DO PROJETO DE INVESTIGAÇÃO

Este projeto de investigação integra-se no Doutoramento em Fisioterapia, sob a orientação da Prof. Dra. Cláudia Silva e co-orientação da Prof. Dra. Ana Rita Pinheiro e Prof. Dr. Miguel Velhote Correia.

O objetivo principal é caracterizar o movimento dos membros superiores e tronco, através da análise de variáveis cinemáticas (do movimento), durante o desempenho das tarefas "acender a luz" e "beber água de um copo", permitindo assim o conhecimento e desenvolvimento de estratégias de reabilitação e aprendizagem motora que promovam a restituição do movimento dos membros superiores de indivíduos com sequelas de acidente vascular cerebral (AVC).

RECOLHA DE DADOS

Para analisar as variáveis cinemáticas, será necessário registar o movimento dos braços e tronco através de câmaras e esferas refletoras. As câmaras só detetam as esferas refletoras. As esferas refletoras serão colocadas no seu corpo por técnicos especializados. Além disso, serão medidos o comprimento dos seus braços e pernas, para ajuste da localização dos objetos envolvidos nas tarefas e para a análise dos dados.

A realização das tarefas será acompanhada pelos mesmos técnicos. Ser-lhe-á pedido que realize três ensaios das tarefas mencionadas com os dois membros superiores, separadamente. Se apresentar um comprometimento sensório-motor moderado, realizará apenas a tarefa "acender a luz". O tempo total de preparação e recolha de dados estimado é de 1 hora. Poderão ser captadas algumas fotografias, apenas para registo da posição postural e interpretação de dados.

A recolha de dados será realizada em dois momentos: o primeiro, após alta hospitalar e o segundo, seis meses após o AVC.

RISCOS

Não há riscos.

BENEFÍCIOS

Os dados recolhidos permitirão o conhecimento e desenvolvimento de ferramentas e estratégias a serem usadas nos processos de reabilitação e aprendizagem motoras dos membros superiores e tronco de indivíduos com sequelas de AVC.

Os indivíduos com sequelas de AVC beneficiarão do incentivo da realização das tarefas funcionais avaliadas - tarefas fundamentais no seu dia a dia – potenciando a sua confiança na concretização destas e de outras tarefas.

Figure 2. Study information delivered to poststroke participants (continued).

GARANTIA DE CONFIDENCIALIDADE

A informação recolhida será colocada numa base de dados segura, protegida por uma palavra-passe e que só pode ser acedida pelos investigadores deste projeto de investigação. Será garantido o anonimato.

COMPENSAÇÃO

Não existem compensações financeiras por participar neste estudo. Será feito reembolso das despesas de transporte, sempre que se justifique.

PARTICIPAÇÃO

A sua participação é voluntária. Pode desistir sem penalização ou perca de benefícios a que possa ter direito, em qualquer momento. Se desistir do estudo antes que a aquisição de dados esteja concluída, os dados serão destruídos ou devolvidos. A recusa em participar ou posterior abandono, não prejudicarão a sua relação com a equipa de clínicos ou investigadores.

CONTACTO

Se tiver alguma dúvida ou questão sobre o projeto de investigação, pode contactar o investigador responsável, Inês Mesquita, através do email ou telemóvel (inesamesquita@gmail.com ou 962469291).

MUITO OBRIGADA PELA SUA COLABORAÇÃO!

Figure 2 - Study information delivered to poststroke participants.

Declaração de consentimento informado

Considerando a "Declaração de Helsínquia" da Associação Médica Mundial

(Helsínquia 1964; Tóquio 1975; Veneza 1983; Hong Kong 1989; Somerset West 1996 e Edimburgo 2000; Washington 2002, Tokyo 2004 e Seoul 2008)

DESIGNAÇÃO DO PROJETO DE INVESTIGAÇÃO

"Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico."

No âmbito do projeto de investigação do Doutoramento em Fisioterapia e do estudo acima designado, **eu, abaixo-assinado, (nome completo)** ____, declaro que compreendi a explicação que me foi fornecida, por escrito e verbalmente, acerca da investigação que se pretende realizar, para a qual é pedida a minha participação, tendo em conta benefícios, possíveis danos, métodos de recolha de dados e forma de tratamento e confidencialidade dos mesmos. Foi igualmente dada a oportunidade para colocar quaisquer questões/dúvidas sobre o assunto e para todas elas ter obtido respostas esclarecedoras. Foi-me garantido que não haverá prejuízo pessoal e foi-me dado tempo suficiente para reflectir sobre esta proposta.

Tomei conhecimento de que, de acordo com as recomendações da Declaração de Helsínquia, a explicação que me foi prestada versou os objectivos da investigação em questão.

Nestas circunstâncias, decido livremente aceitar participar neste projeto de investigação, tal como foi apresentado pela investigadora.

Data: ___/___/ _____

Assinatura do(a) Inquirido(a):

____

Assinatura do responsável pelo projeto de investigação:

____

(Inês Albuquerque Mesquita)

Figure 3 – Informed consent delivered to healthy participants.

Declaração de consentimento informado

DESIGNAÇÃO DO PROJETO DE INVESTIGAÇÃO

"Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico."

Eu, abaixo-assinado, (nome completo) ____:

Fui informado de que o estudo de investigação acima mencionado se destina a caracterizar o movimento do membro superior e tronco de indivíduos sem patologia e indivíduos com sequelas de acidente vascular encefálico.

Sei que neste estudo está prevista a realização de questionários, tendo-me sido explicado em que consistem e que se destinam a verificar se preencho os critérios de inclusão para participar no estudo.

Também sei que se preencher os critérios de inclusão serei convidado(a) a participar no estudo após alta hospitalar e que as recolhas de dados serão realizadas no Laboratório de Biomecânica da Universidade do Porto.

Foi-me garantido que todos os dados relativos à identificação dos Participantes neste estudo são confidenciais e que será mantido o anonimato.

Sei que posso recusar-me a participar ou interromper a qualquer momento a participação no estudo, sem nenhum tipo de penalização por este facto.

Compreendi a informação que me foi dada, tive oportunidade de fazer perguntas e as minhas dúvidas foram esclarecidas.

Aceito participar de livre vontade no estudo acima mencionado.

Também autorizo a divulgação dos resultados obtidos no meio científico, garantindo o anonimato.

Data: ___/___/ _____

Assinatura do(a) Inquirido(a):

____

Assinatura do responsável pelo projeto de investigação:

____

Figure 4 – Informed consent delivered to poststroke participants.

APPENDIX III – Sample characterization questionnaires

Doutoramento em Fisioterapia - Inês Albuquerque Mesquita

Caracterização do movimento do membro superior e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular encefálico

Código de Identificação:_____________

QUESTIONÁRIO

RESUMO DO PROJETO DE INVESTIGAÇÃO

O presente questionário integra-se no projeto de investigação de Doutoramento em Fisioterapia, sob a orientação da Prof. Dra. Cláudia Silva e co-orientação da Prof. Dra. Ana Rita Pinheiro e Prof. Dr. Miguel Velhote Correia.

O objetivo principal deste projeto é caracterizar o movimento do membro superior, através da análise de variáveis cinemáticas, durante o desempenho das tarefas "acender a luz" e "beber água de um copo", permitindo assim o conhecimento e desenvolvimento de estratégias de reabilitação e aprendizagem motora que promovam a restituição do movimento do membro superior de indivíduos com sequelas de acidente vascular encefálico (AVE).

GARANTIA DE CONFIDENCIALIDADE

A informação recolhida será colocada numa base de dados segura, protegida por uma palavra-passe e que só pode ser acedida pelos investigadores deste projeto de investigação. Será garantido o anonimato.

QUESTÕES

1. É destro? _____________

Se não é destro, agradecemos a sua colaboração e disponibilidade, mas o seu questionário termina aqui!

2. Qual é a sua idade? _____________

Se tem idade inferior a 30 anos, agradecemos a sua colaboração e disponibilidade, mas o seu questionário termina aqui!

3. Qual é o seu sexo?

Feminino ☐ Masculino ☐

4. Qual é a sua altura? _________ centímetros
5. Qual é o seu peso? _________ quilogramas

Figure 1. Healthy sample characterization questionnaire (continued)

6. Atualmente, toma alguma medicação?

Sim ☐ Não ☐

6.1 Se **sim**, indique qual/quais.______________________________

7. Assinale a sua situação profissional atual:

Estudante ☐ Empregado ☐ Desempregado ☐ Reformado ☐

7.1 Se selecionou a opção **EMPREGADO**, qual/quais é/são a(s) sua(s) atividade(s) profissional/profissionais.______________________________

7.2 Se selecionou a opção **EMPREGADO**, há quanto tempo exerce essa(s) atividade(s) profissional/profissionais.______________________________

7.3 Se selecionou a opção **EMPREGADO**, já exerceu outra(s) atividade(s) profissional/profissionais diferente(s)?

Sim ☐ Não ☐

7.3.1 Se **sim**, indique qual/quais.______________________________

7.3.2 Se **sim**, durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?______

____

7.4 Se selecionou a opção **DESEMPREGADO**, já exerceu alguma(s) atividade(s) profissional/profissionais?

Sim ☐ Não ☐

7.4.1 Se **sim**, indique qual/quais.______________________________

7.4.2 Se **sim**, durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?______

____

7.5 Se selecionou a opção **REFORMADO**, indique que atividade(s) profissional/profissionais exerceu.______________________________

7.5.1 Durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?____________

____

Figure 1. Healthy sample characterization questionnaire (continued)

8. Atualmente, apresenta algum problema músculo-esquelético ou neurológico que afete a função dos seus braços e/ou tronco?

Sim ☐ Não ☐

8.1 Se sim, indique qual/quais. ______________________________

9. Atualmente, apresenta dor nos seus braços, tronco e/ou cervical?

Sim ☐ Não ☐

10. No passado, já teve algum problema músculo-esquelético ou neurológico que afetasse a função dos seus braços e/ou tronco? (considere também problemas consequentes de acidentes rodoviários e quedas)

Sim ☐ Não ☐

10.1Se sim, indique qual/quais. ______________________________

11. Já foi operado aos braços, tronco e/ou cervical?

Sim ☐ Não ☐

11.1 Se sim, indique que cirurgia(s) fez.______________________________

MUITO OBRIGADA PELA SUA COLABORAÇÃO!

Página 3

Figure 1. Healthy sample characterization questionnaire.

Doutoramento em Fisioterapia - Inês Albuquerque Mesquita

Caracterização do movimento dos membros superiores e tronco de indivíduos sem patologia e de indivíduos com sequelas de acidente vascular cerebral

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FACULDADE DE DESPORTO
UNIVERSIDADE DO PORTO

Código de Identificação:_____________

QUESTIONÁRIO

AVC

1. Data da ocorrência:____________________
2. Primeiro? Sim ☐ Não ☐ Observações:________________________________
3. Unilateral? Sim ☐ Não ☐ Observações:________________________________
4. Território vascular:____
5. Tipo: Isquémico ☐ Hemorrágico ☐
6. Localização:____
7. Extensão do AVC:____

8. Idade: _____________
9. Sexo? Feminino ☐ Masculino ☐
10. Destro? _____________
11. Altura: ________ centímetros
12. Peso: ________ quilogramas

OUTRAS CONDIÇÕES DE EXCLUSÃO DO ESTUDO

13. Apresenta negligência hemi-espacial, alterações visuais não corrigidas e défices cognitivos diagnosticados pelo neurologista, que comprometam a compreensão e realização do protocolo experimental?

Sim ☐ Não ☐

Observações:

____

____

Figure 2. Poststroke participants characterization questionnaire (continued).

14. Excluindo as sequelas do acidente vascular cerebral (AVC), apresenta outro(s) problema(s) músculo-esquelético(s) ou neurológico(s) que afete(m) a função dos seus braços e/ou tronco?

Sim ☐ Não ☐

14.1 Se sim, indicar qual/quais. ____________________

15. Atualmente, apresenta dor nos seus braços, tronco e/ou cervical?

Sim ☐ Não ☐

16. No passado, já teve algum problema músculo-esquelético ou neurológico que afetasse a função dos seus braços, tronco e/ou cervical? (considerar também problemas consequentes de acidentes rodoviários e quedas)

Sim ☐ Não ☐

16.1 Se sim, indique qual/quais. ____________________

17. Já foi operado aos braços, tronco e/ou cervical?

Sim ☐ Não ☐

17.1 Se sim, indicar que cirurgia(s) fez. ____________________

18. Atualmente, toma alguma medicação?

Sim ☐ Não ☐

18.1 Se sim, indicar qual/quais. ____________________

SITUAÇÃO PROFISSIONAL

19. Situação profissional imediatamente anterior à ocorrência do AVC:

Estudante ☐ Empregado ☐ Desempregado ☐ Reformado ☐

19.1 Se selecionou a opção **EMPREGADO**, indicar qual/quais é/são a(s) atividade(s) profissional/profissionais. ____________________

19.2 Se selecionou a opção **EMPREGADO**, indicar há quanto tempo exerce essa(s) atividade(s) profissional/profissionais. ____________________

19.3 Se selecionou a opção **EMPREGADO**, indicar se já exerceu outra(s) atividade(s) profissional/profissionais diferente(s)?

Sim ☐ Não ☐

19.3.1 Se sim, indicar qual/quais. ____________________

Figure 2. Poststroke participants characterization questionnaire (continued).

19.3.2 Se **sim**, indicar durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?

____

19.4 Se selecionou a opção **DESEMPREGADO**, indicar se já exerceu alguma(s) atividade(s) profissional/profissionais?

Sim ☐ Não ☐

19.4.1 Se **sim**, indicar qual/quais.____

19.4.2 Se **sim**, durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?

____

19.5 Se selecionou a opção **REFORMADO**, indicar que atividade(s) profissional/profissionais exerceu.____

19.5.1 Durante quanto tempo exerceu essa(s) atividade(s)profissional/profissionais?__________

____

FIM DO QUESTIONÁRIO

Figure 2. Poststroke participants characterization questionnaire.

APPENDIX IV – Fugl-Meyer Assessment for Upper-Extremity

FUGL-MEYER ASSESSMENT

Código de Identificação_________________________________ Data_________________

MEMBRO SUPERIOR

OMBRO/COTOVELO/ANTEBRAÇO

I. Actividade Reflexa

Flexores – Bicipete ☐
- Flexores dos dedos ☐
Extensores – Tricipete ☐

II. a. Sinergia dos Flexores

Ombro - Retracção ☐
- Elevação ☐
- Abdução ☐
- Rotação externa ☐
Cotovelo- Flexão ☐
Antebraço – Supinação ☐

b. Sinergia dos Extensores

Ombro – Adução/rotação interna ☐
Cotovelo – Extensão ☐
Antebraço – Pronação ☐

III. Mão para coluna lombar

Mão – Avança para a col. lombar ☐
Ombro - Flexão 0°-90° ☐
Cotovelo - Pronação/supinação ☐

IV. Ombro- Abdução 0°- 90° ☐
- Flexão 90°- 180° ☐
Cotovelo 0°- Pronação/Supinação ☐

V. Actividade reflexa normal ☐

A. PUNHO

Cotovelo 90° - Estabilidade do punho ☐
Cotovelo 90° - Flexão/Extensão do punho ☐
Cotovelo 0° - Estabilidade do punho ☐
Cotovelo 0° - Flexão/Extensão do punho ☐
Circundução ☐

B. MÃO

Flexão conjunta dos dedos ☐
Extensão conjunta dos dedos ☐
Garra a ☐
Garra b ☐
Garra c ☐
Garra d ☐
Garra e ☐

D. COORDENAÇÃO/VELOCIDADE

Tremor ☐
Dismetria ☐
Velocidade ☐

Total Motora para a Extremidade Superior ☐

APPENDIX V – International Physical Activity Questionnaire

Questionário Internacional da Atividade Física (IPAQ) – Versão Curta

Código de Identificação: ___________

Este questionário inclui questões sobre a atividade física que realiza habitualmente para se deslocar de um lado para outro, atividades domésticas (femininas ou masculinas), jardinagem e atividades que efetua no seu tempo livre para entretenimento, exercício ou desporto. As questões referem-se à atividade física que realiza numa semana normal, e não em dias excecionais. Por favor, responda a todas as questões mesmo que não se considere uma pessoa ativa.

Ao responder às seguintes questões considere o seguinte:

- **Atividades físicas vigorosas** referem-se a atividades que requerem um esforço físico intenso e que fazem ficar com a respiração ofegante.
- **Atividades físicas moderadas** referem-se a atividades que requerem esforço físico moderado e tornam a respiração um pouco mais intensa que o normal.

Ao responder às questões, considere apenas as atividades físicas que realize pelo menos **10 minutos seguidos**.

Q1. Diga-me, nos últimos 7 dias, em quantos dias fez atividades físicas vigorosas, como por exemplo, levantar objetos pesados, cavar, ginástica aeróbica, nadar, jogar futebol, andar de bicicleta a um ritmo rápido?

|____| Dias

Q2. Nos dias em que pratica atividades físicas vigorosas, quanto tempo em média dedica normalmente a essas atividades?

|____| Horas |____| Minutos

Q3. Diga-me, <u>nos últimos 7 dias</u>, em quantos fez atividades físicas moderadas, como por exemplo, carregar objetos leves, caçar, trabalhos de carpintaria, andar de bicicleta a um ritmo normal ou ténis de pares? Por favor não inclua o "andar".

Dias

Q4. Nos dias em que pratica atividades físicas moderadas, quanto tempo em média dedica normalmente a essas atividades?

Horas Minutos

Q5. Diga-me, <u>nos últimos 7 dias</u>, em quantos dias andou pelo menos 10 minutos seguidos?

Dias

Q6. Quanto tempo no total, despendeu num desses dias, a andar/ caminhar?

Horas Minutos

Q7. Num dia normal, quanto tempo passa sentado?

Horas Minutos

Q8. Num dia normal, quanto tempo dedica a ver televisão?

Horas Minutos

Muito obrigado pela sua atenção!